Project Number 282910

ÉCLAIRE

Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems

Seventh Framework Programme

Theme: Environment

D18.4 Scenario analysis to include policy recommendations and advice to other interest groups

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Dissemination Level		
PU	Public	☐
PP	Restricted to other programme participants (including the Commission Services)	☒
RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

The effects for assessment of this work package are to assess the economic value of impacts of atmospheric nitrogen and ozone on:

1. Terrestrial biodiversity
2. Crop production
3. Forest production
4. Carbon sequestration

These effects were selected as being particularly relevant to the pollutants of interest to ECLAIRE, and had the potential for quantification drawing on the outputs of other components of the study. It is noted that the methods and outputs of the analysis need to be in a form that can be integrated with cost-benefit analysis of European air quality policies. With this in mind, the analysis presented here includes also assessment of health impacts, to enable some discussion of the role of quantification of ecosystem damage in European CBA work.

Deliverable 18.3 provided information on the development of methods for the economic assessment under ECLAIRE. The deliverable presented here provides analysis of the final scenarios for ECLAIRE using, and in some cases extending, the methods previously developed.

2. Objectives:

Quantification of changes in the value of ecosystem services resulting from scenarios developed for the ECLAIRE study. It is important to recognise that we are dealing with change, rather than seeking to provide an overall value of specific ecosystem services. In some cases the two go hand in hand, for example when dealing with agricultural or forest production. In others, particularly for biodiversity, the issue of modelling change is more problematic as the significance of change is harder to gauge and to communicate.

A second objective is to ensure that the methods defined in this Deliverable can be applied rapidly for policy analysis (specifically CBA) for the European Commission. A consequence of this is that available models have been simplified in order that quantification can be carried out using standard outputs from IIASA's GAINS model. Consideration is then given to the extent to which the simplified modelling reflects the results of more detailed models.

A third objective has been to assess the potential consequences of climate change on crop distributions in Europe, and the interaction of these changes with the impacts of ozone.

3. Activities:

Discussions have been held with various members of the ECLAIRE team through a series of meeting and workshops (listed below). This has improved the consistency of the analysis presented in this Deliverable with other ECLAIRE activities.

4. Results:

Table (i) summarises estimates presented here of the economic value of damage to ecosystems from ozone and nitrogen deposition, and to health from exposure to fine particles and ozone. Table (ii) provides estimates of the benefits of moving from the current legislation (CLE) scenario to the BIO75 policy scenario and MFR (maximum feasible reduction) scenario in 2030 and 2050. Shading in the tables indicates alternative estimates for the same effect, and results for any scenario within the same group (i.e. the 2 estimates for crop production and the 3 estimates for biodiversity) should not be added together. The row titled 'Ecosystems aggregate effect' seeks to provide some overall summary of several rows of data: however, it Is accepted that results can be added in different ways to obtain different totals according to any individuals view on which estimates are most robust.

Table (i) Summary of damage estimates, all figures €billion/year

	CLE	**CLE**	**CLE**	**BIO75 i77**	**MFR**
	2000	**2010**	**2030**	**2030**	**2030**
Crops	9.2	7.9	6.6	6.5	6.2
Crops (climate adj)	n/a	n/a	8.9	n/a	8.4
Forest, climate	1.3 - 15	1.1 - 14	4.0 - 31	4.0 - 30	3.8 - 29
Forest production	2.4 - 3.7	2.1 - 3.3	1.9 - 3.0	1.9 - 2.9	1.8 - 2.8
Biodiversity (WTP)	4.3 - 13	3.8 - 11	3.2 - 9.5	2.7 - 8.0	2.3 - 6.8
Biodiversity (repair cost)	15	12	9	7	6
Biodiversity (Reg. rev. pref)	n/a	n/a	n/a	n/a	n/a
Health	460	320	210	180	160
Health (range)	350 - 1500	240 - 1200	160 - 930	140 - 780	120 - 710

	CLE	**BIO75 i78**	**MFR**
	2050	**2050**	**2050**
Crops	6.5	6.4	6.2
Crops (climate adj)	11.8	n/a	11.1
Forest, climate	4.0 - 30	3.9 - 30	3.8 - 29
Forest production	1.9 - 2.9	1.9 - 2.9	1.8 - 2.8
Biodiversity (WTP)	3.2 - 9.6	2.6 - 7.8	2.2 - 6.7
Biodiversity (repair cost)	9	7	6
Biodiversity (Reg. rev. pref)	n/a	n/a	n/a
Health	190	160	140
Health (range)	150 - 1000	120 - 860	110 - 780

Table (ii) Summary of benefit estimates relative to current legislation (CLE) scenario for each year, all figures €billion/year

	BIO75 i77	**MFR**	**BIO75 i78**	**MFR**
	2030	**2030**	**2050**	**2050**
Crops	0.10	0.4	0.11	0.4
Crops (climate adj)		0.50		0.70
Forest, climate	0.04 - 3.0	0.16 - 1.2	0.04 - 0.30	0.16 - 1.2
Forest production	0.02 - 0.03	0.07 - 0.11	0.02 - 0.03	0.07 - 0.11
Biodiversity (WTP)	0.51 - 1.5	0.91 - 2.7	0.61 - 1.8	1.0 - 2.9
Biodiversity (repair cost)	1.8	3.0	2.2	3.1
Biodiversity (Reg. rev. pref)		11		11
Ecosystems mid estimate	**1.2**	**2.5**	**1.4**	**2.8**
Health	30	50	30	50
Health (range)	20 - 150	40 - 220	30 - 140	40 - 220

Overall, the estimates of ecosystem benefits add about 5% to the estimate of potential benefit of the scenarios considered, with health benefits quantified using the assumptions (centred on the ‘median value of a life year/VOLY’ estimate) most widely referenced in the European Commission’s work in this field. For effects on crops and forests, potential benefits are limited by the small extent to which ozone levels can be reduced using the abatement options contained in the GAINS model.

It is logical to ask what these estimates of ecosystem damage add to the overall policy message emerging from the ECLAIRE work. We offer the following thoughts:

1. The analysis of crops highlights the importance of accounting for future changes in cropping patterns across Europe as a consequence of climate change, with some species (e.g. tomato) likely to be planted in greater quantity than at present, and others (e.g. wheat) making way for them to some extent. Comparing the ‘climate adjusted’ crop damage/benefit estimates above with the unadjusted values demonstrates an overall increase in sensitivity to ozone over time.
2. Analysis should be extended to include damage to livestock production and related products (milk, wool) as these account for 50% of the EU’s agricultural output (though

it is accepted that animal products may not be so sensitive to pollution effects, partly as negative impacts can be ameliorated using additional feed at a cost).

3. For forests the more important impact of the two assessed was of ozone reducing levels of carbon sequestration, as opposed to its impact on gross output of the forestry and logging sector. Estimates of the damage arising from reduced carbon sequestration increase markedly for the later scenarios given a step change in the values adopted for that period.
4. It is acknowledged that the valuation of carbon sequestration is problematic. The debate on appropriate values to adopt per tonne of CO_2 is not likely to go away soon. The values selected here were in part chosen to highlight the variation in available estimates from well regarded sources and show at the lower end effects of a similar magnitude to effects on production from forestry and logging. However, at the upper end, results for climate mitigation are substantially greater.
5. The health impact assessment and valuation demonstrates the case for reducing air pollutant emissions across Europe. The numbers generated here, whilst smaller than those for health, show that other impacts are not inconsequential. This in turn indicates that policy can be made most efficiently if it focuses on a wider range of effects rather than a limited selection, with potential benefits in the order of €billions per year.

It is necessary to consider the validity of any of the methods for quantifying damage to biodiversity. Comments have already been made, principally about the validity of the repair cost approach and ‘regulatory revealed preference’ approach, with the willingness to pay (WTP) based estimates here considered superior from the perspective of economic theory. However, the approach is not without its flaws. The assumptions that individuals are able to either assess the full societal value of biodiversity, or pay for its protection, are, at best, questionable. A bid in a valuation study will be subject to a number of factors including ability to pay, and individuals may consider that additional improvements beyond what they can personally contribute to should be undertaken.

The result of the ‘regulatory revealed preference’ method in generating higher estimates implies that policy makers in setting the ultimate goal of European policy on biodiversity place a much higher value on ecological protection than members of the public. This goal, under Target 2 of the EU’s Biodiversity Strategy to 2020, is phrased as ‘no net loss of biodiversity or ecosystem services’. Of course, it is doubtful that they considered the costs of reducing air pollution when agreeing the policy, but far-reaching objectives like this rarely come cheap.

It is noted that the values used within each method for assessing biodiversity impacts are drawn from a limited literature. The WTP estimates could certainly be refined through surveys carried out in a number of countries, focused on deriving values that feed into assessment of marginal changes linked to developing policy. This is identified as the most pressing research need from this Work Package. Part of this work should seek to elucidate what members of the public know about the impacts of air pollution and threats to ecosystems more generally.

5. Milestones achieved:

MS81: Finalisation of results.

6. Deviations and reasons:

There were no deviations.

7. Publications:

Publications are in preparation covering:

- Impacts to crops (EMRC, University of Aarhua, NERC)
- Impacts to forests (SEI/University of York, EMRC)
- Impacts to ecosystems (EMRC, NERC, RIVM)

8. Meetings:

The development of this report has been informed through a series of meetings, in particular:

- Meeting at CEH, Bangor, March 2015
- Component 5 workshop, IIASA, June 2015
- Final ECLAIRE Congress, Edinburgh, September 2015.

9. List of Documents/Annexes:

Impacts to the environment and human health under the ECLAIRE scenarios Deliverable 18.4

Impacts to the environment and human health under the ECLAIRE scenarios

ECLAIRE Project, Work package 18

Deliverable 18.4

Authors:

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Patrick Bueker, Lisa Emberson (effects on carbon sequestration by forests and on forest productivity)
Stefan Åstrom, IVL (valuation of forest impacts)
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October 2015

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Summary

1 Introduction

1.1 Objectives

1.1.1 ECLAIRE objectives

The ECLAIRE Project (Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems), funded by European Commission DG Research under the 7th Framework Programme, has the following broad objectives of relevance to the present report:

- To investigate the ways in which climate change alters the threat of air pollution (NOx, NH_3 and ozone) on European land ecosystems including soils. This includes the development of response relationships based on field observation, experimental data and modelling.
- To quantify how climate change alters ecosystem vulnerability to tropospheric O_3 and N deposition, including interaction with increased CO_2. Combined with special topics on interactions with N form (wet/dry, NHx/NOy), aerosol-exacerbated drought stress and BVOC self-protection of O_3 effects, novel threshold and dose-response approaches will be developed.
- To estimate interactions and feedbacks on plant and soil carbon stocks, greenhouse gas balance and plant species change.
- To apply the new risk assessment chain at the European scale, to assess how projected climate change will alter damage estimates, in part through economic valuation of ecosystem services. Improved integrated assessment modelling will allow cost-benefit analysis to better inform future mitigation and adaptation strategies on air pollution and climate change.

1.1.2 Work Package 18 objectives

Within the Project, Work Package 18 is designed to derive economic impacts and valuation of changes1 in ecosystem services through the following objectives:

- To link the concept of ecosystem services with existing mapping of European ecosystems and pollutant impacts.
- To characterise the links between pollutant exposure, impact and value to permit quantification of pollutant damage.
- To assess change in the value of ecosystem services across different scenarios using a marginal approach to the extent possible.
- To prioritise gaps in the existing knowledge base such that further research can be targeted on the parameters likely to have the greatest economic impact.

A constraint on the analysis is that ECLAIRE does not include original valuation work, but is instead focused on the application of available valuation studies to the ECLAIRE outputs.

1.1.3 Objectives of this report

The primary objective of this deliverable is to provide a quantification of the impacts to ecosystem services under the ECLAIRE scenarios, using the methods developed under the study and defined through Deliverable 18.3. For comparison, health impacts have also been quantified to permit comparison of the different types of impact relevant to policy analysis.

A second objective is to integrate models into the cost-benefit analysis tools used to provide the European Commission with policy advice. This requires some simplification of the more

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[1] The focus on change is important: the analysis does not seek to ascribe value to the totality of European environmental service, but to the change arising from moving between different policy scenarios.

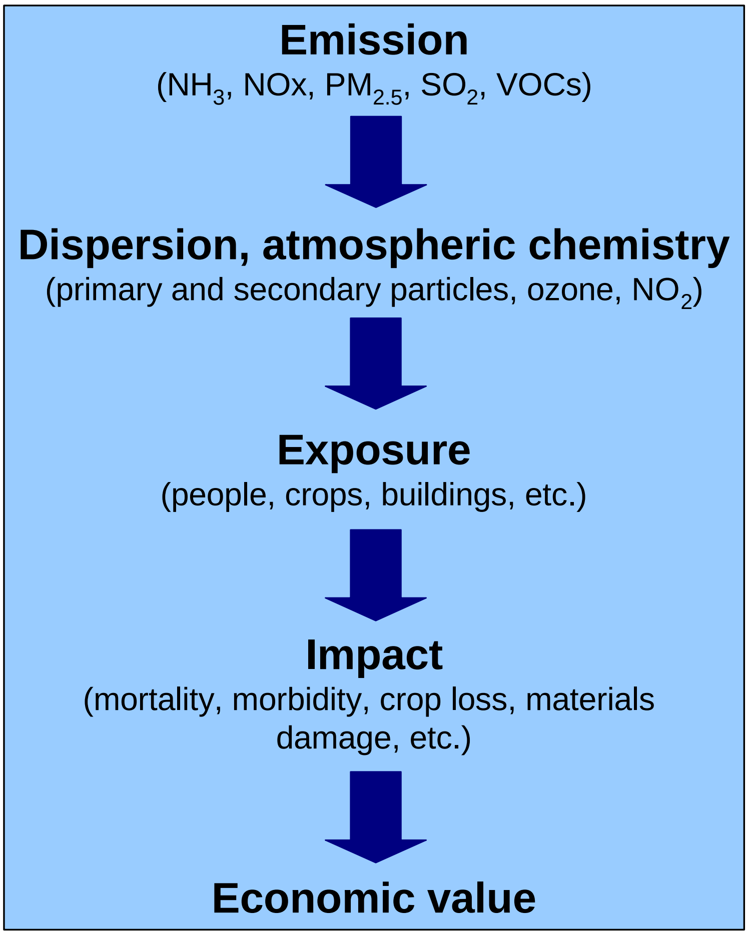
sophisticated tools generated and used by other modelling groups involved in the ECLAIRE Project.

A third objective is to assess the effects of climate change on the distribution of crops across Europe, and then to investigate how this may change ozone related impacts. The same has not been considered necessary for forests because the time horizon of the scenarios considered here extends only to 2050, and the pace of change in the forestry sector is slow given the long rotation times of forests compared to crops.

1.2 Overview of methods

The basis for the methods used here is the impact pathway approach developed under the ExternE project (ExternE, 1995, 1999, 2005) and the CBA for the Clean Air For Europe (CAFE) Programme, and illustrated in Figure 1. This approach follows a logical progression from emission, through dispersion and exposure to quantification of impacts and their valuation.

Figure 1. Impact Pathway Approach, tracing the consequences of pollutant release from emission to impact and economic value.



The general form of the equation for the calculation of impacts is:

Impact = Pollution level x Stock at risk x Response function

Pollution may be expressed in terms of:

- **Concentration**, for example in the case of impacts to human health where exposure to the pollutants of interest to this study occurs through inhalation, or

- **Deposition**, for example in the case of damage to building materials where damage is related to the amount of pollutant deposited on the surface.

The term ‘stock at risk’ relates to the amount of sensitive material (people, ecosystems, materials, etc.) present in the modelled domain. For the health impact assessment, account is taken of the distribution of population and of effects on demographics within the population, such as children, the elderly, or those of working age. Incidence and prevalence rates are used to modify the stock at risk for each type of impact quantified. Improved data availability has enabled this report to use country-specific rate data to a much greater degree than before.

1.3 Scenarios

Scenarios have been provided for the years 2000, 2010, 2030 and 2050, representing emissions under current legislation. For 2030 and 2050 two further scenarios are provided, MFR (Maximum Feasible Reduction when applying all abatement measures included in the GAINS model) and BIO75, representing 75% gap closure for impacts (the ‘gap’ representing the distance between the CLE and MFR scenarios, hence 75% gap closure reduces impacts by 75% of what is considered possible).

Table 1. List of scenarios quantified in this analysis

GAINS scenario label	Spreadsheet label	Years
V5_ECLAIRE_CLE	V5_ECLAIRE_CLE	2000, 2010, 2030, 2050
V5_ECLAIRE_opt_2030_i77	V5_ECLAIRE BIO75 i77	2030
V5_ECLAIRE_MFR_opt_2030	V5_ECLAIRE MFR	2030
V5_ECLAIRE_opt_2050_i78	V5_ECLAIRE BIO75 i78	2050
V5_ECLAIRE_MFR_opt_2050	V5_ECLAIRE MFR	2050

2 Crop damage assessment

2.1 General approach for crop impact assessment

In recent years, experts in assessment of crop damage have developed a strong preference for quantification using a measure of dose (referred to as POD_y, the phytotoxic ozone dose in excess of some threshold *y*) rather than a measure of concentration (generally expressed as 'AOT40', the accumulated exposure to ozone in excess of 40 ppb over the growing season). The dose metric is preferred as high-ozone conditions with high temperatures may lead to low ozone uptake given limited water availability. Unfortunately, POD relationships are available for very few crops – wheat, tomato and potato at the present time. In order to gain an understanding of the overall effect on crop production it is therefore necessary to make some judgement of the relative sensitivity of a large number of crops compared to those for which POD data are available. This was explored in Deliverable 18.3, where available response functions were extrapolated to all crops, using data on differential sensitivity to ozone. Further information is given below.

Further consideration is given below to how crop production will change in Europe in response to climate change. Climate change will cause farmers to switch to different crops that can withstand altered conditions with respect to rainfall, temperature, etc.

2.2 Methods for crop impact assessment

2.2.1 Basic analysis

Analysis proceeds through the following steps:
Step 1: Obtain crop production data as economic value of production
Step 2: Convert production data from international $ to euro
Step 3: Define response functions
Step 4: Define geographic resolution
Step 5: Obtain ozone data
Step 6: Apply response functions and calculate impacts

Each step is described below.

Step 1: Obtain crop production data

European crop production data for 2010 was extracted from the UN Food and Agriculture Organization (FAO) as gross production, 000 $int[2]. The response functions indicate a linear relationship between the selected metric of ozone exposure and yield. Assuming that the value of yield loss over the range of possible changes in ozone exposure is also linear, it is possible to use the change in economic production directly. If it is assumed that the value of crops does not vary in a linear fashion with yield over the range of interest it may be necessary to go first through a calculation of the change in yield and then to valuation, but this would be a simple addition to the analysis.

Step 2: Convert production data to euro

Int$ 2004-6 are converted to 2005 € using a conversion factor of 0.8912. Note: all cost data in the GAINS and ALPHA-Riskpoll Cost-Benefit Assessment models are expressed in price year 2005.

Step 3: Define response functions

Response functions identified for each crop type:

For wheat, relative yield = 1 – POD3IAM * 0.0064 (ICP M&M, 2014)

POD relationships are also available for tomato and potato, but only against the POD6 metric, which differs to POD3IAM with respect to both threshold and the period over which ozone data are assessed (55 days vs 90 days). We take the following functions expressed against POD6 and then pro-rate against the what POD3IAM function:

For wheat, relative yield = 1- POD6 *0.038 (ICP M&M, 2014)

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[2] http://faostat3.fao.org/download/Q/QV/E.

For potato, relative yield = 1- POD6 *0.013 (ICP M&M, 2014)
= 1 – POD3IAM * (0.0064 * 0.013/0.038)
= 1 – POD3IAM * 0.0022
For tomato, relative yield = 1- POD6 *0.0266 (Gonzalez-Fernandez et al)
= 1 – POD3IAM * (0.0064 * 0.0266/0.038)
= 1 – POD3IAM * 0.0045

For a number of other crops information on sensitivity is taken from table 1 (their numbering) of ICP Vegetation (2011):

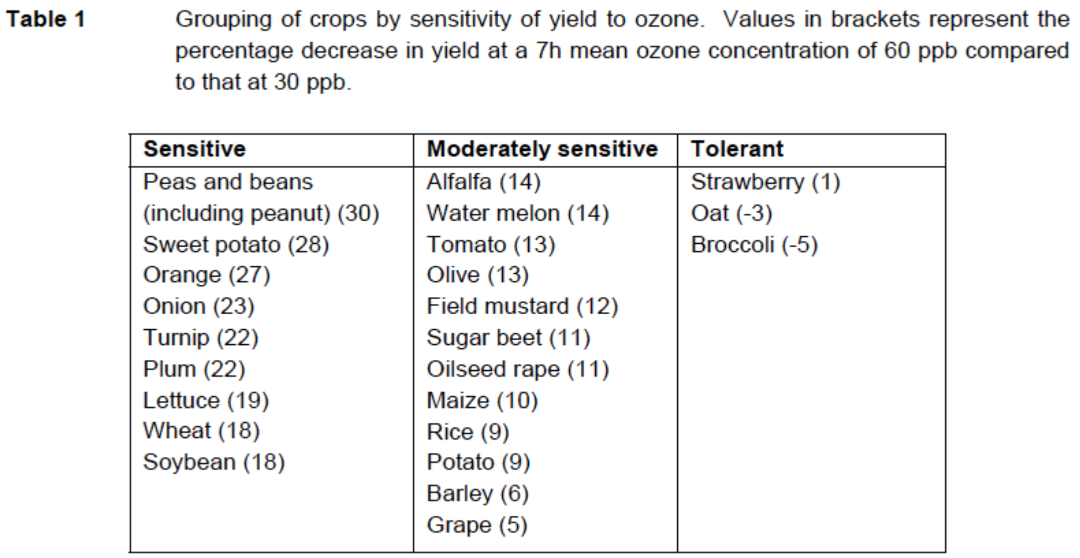

Table 1 Grouping of crops by sensitivity of yield to ozone. Values in brackets represent the percentage decrease in yield at a 7h mean ozone concentration of 60 ppb compared to that at 30 ppb.

Sensitive	**Moderately sensitive**	**Tolerant**
Peas and beans (including peanut) (30)	Alfalfa (14)	Strawberry (1)
Sweet potato (28)	Water melon (14)	Oat (-3)
Orange (27)	Tomato (13)	Broccoli (-5)
Onion (23)	Olive (13)	
Turnip (22)	Field mustard (12)	
Plum (22)	Sugar beet (11)	
Lettuce (19)	Oilseed rape (11)	
Wheat (18)	Maize (10)	
Soybean (18)	Rice (9)	
	Potato (9)	
	Barley (6)	
	Grape (5)	

For these crops (excluding wheat, potato and tomato, as POD3IAM functions are derived as above), functions are derived relative to POD3IAM by scaling against wheat yield loss. Hence peas and beans are taken to be 30/18 times as sensitive as wheat, and grape 5/18 times as sensitive. It is considered unlikely that ozone is beneficial to oat or broccoli, so for these crops the response function is set to zero.

For other crops some extrapolation is applied where possible. So, for example, simple cereals such as rye are regarded like oat as being tolerant, and legumes generally are regarded like peas and beans as being highly sensitive.

Other crops not covered by the functions derived so far are taken to have similar sensitivity to grape, the least sensitive of the crops in the ‘moderately sensitive’ class of the table above. The logic for adopting the function for the least sensitive of the ‘moderately sensitive’ crops is that experimentation tends to focus on species and cultivars for which a significant response has been observed at some time. A lack of data for a crop might therefore suggest that it is unlikely to be highly sensitive, and hence that it is either tolerant or moderately sensitive. The sensitivity of grape is thus taken as indicative of the break point between the two sensitivity classes.

For sensitivity analysis a low variant has been adopted. Wheat, tomato and potato functions are as above. Crops identified as ‘sensitive’ are given the same sensitivity as wheat, the least sensitive of the ‘sensitive’ species in Table 1. Tolerant crops are given a DRF of 0. All other crops are given the same sensitivity as grape, the least sensitive of the ‘moderately sensitive’ crops in the above table.

Step 4: Define geographic resolution
The ozone data provided for scenario analysis in policy development for the European Commission are provided at national level only, though represent a receptor-weighted average for each country. The geographic resolution adopted here is thus the national scale.

Step 5: Obtain ozone exposure data.
Ozone data for the scenarios listed in Table 1 were provided by IIASA for the analysis (Chris Heyes, IIASA< personal communication).

Step 6: Application of the response functions.
Existing production data are of course depressed as a result of exposure to current levels of ozone. A first stage is therefore to quantify a counter-factual level of production, assuming that ozone levels (here, as POD3IAM) = 0. This is calculated for each country using the following expression, where DRF = dose response function:

$$Yield\ at\ zero\ ozone = \frac{2010\ yield}{1 - [POD3IAM \times DRF]}$$

Hence if ambient ozone in 2010 reduced yield of a crop by 20% (the product of POD3IAM and DRF), the yield at zero ozone would have been 25% higher than reported production.

Assuming that crop production patterns remain unchanged, the impacts of ozone in future years can then by calculated as follows:

$Impact_y = 2010\_production * POD3IAM_y * DRF$

Where the subscript *y* refers to the target year for quantification.

2.2.2 Estimating baseline crop production under a changing climate

Data
Climate data, at a 14km x 14km grid scale is provided by CMCC, via EU FP7 BASE project. The data is based on the outputs of the latest version of the high resolution Regional Climate Model (RCM) developed at the Rossby Centre, the climate modelling research unit of the Swedish Meteorological and Hydrological Institute (SMHI). For this study, two climate variables namely monthly temperature and precipitation are used. For future projection, the RCP 4.5 scenario is used and the temporal focus is for the years 2030 and 2050.
Land use data is obtained for the year 2004 at a 1km x 1km resolution covering 25 countries (Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom). These data have been made available from JRC, based on CAPRI (Common Agricultural Policy Regionalised Impact) modelling system. The land use data considers a list of the most abundant crop types within the EU25 area. For modelling efficiency and considering the available crop production data, the land use data is aggregated into 21 classes: wheat, barley, rye, oat, other cereals, apples, citrus, other fruits, grapes, maize, rapeseed, sunflower, soya, other oil seeds, olives, other crops, potatoes, sugar beet, tomatoes, other vegetable, and rice paddy.

Crop production data is sourced from FAO (as above). This provides the value of gross agricultural production for the year 2010 (at 2004-2006 International Dollar Prices, consistent with the price year of 2005 used in the GAINS modellilng) for 115 crops, which are then aggregated to match the classification of the land use data. The value is then converted to Euros. The agricultural production is available for the 25 countries included in the present study. Data on area harvested of the different crops in each of the 25 countries is also extracted from FAO and is used for estimating the production value per hectare in each country.

Land use modelling
A land use share model framework is adopted for modelling the climatic influence of agricultural land use in the future (Nainggolan et al., 2014, Termansen et al., 2014, Nainggolan et al., 2015). The choice of the framework is inspired by previous studies (Lichtenberg, 1989; Wu and Segerson, 1995; Plantinga, 1996). In the implementation of the model, we employed fractional logit model (Papke and Wooldridge, 1996). The model is spatially explicit and can in principle be developed at the resolution of the 1km x 1km. The model is estimated for the reference situation of 2004, the latest year for which land use data exist. As explanatory variables, the model takes temperature and precipitation in both linear

and quadratic terms. On the basis of the estimation results, projection of agricultural land use share under future changing climate is subsequently undertaken.

The agricultural land use share projection is used to calculate the reallocation of agricultural land for different crops for the year 2030 and 2050. The total amount of land available for agriculture in each of the 25 countries is fixed to that of the year 2010 hence assuming no further expansion of agricultural land. Given the strong EU position on environmental protection, this assumption on capping the area devoted for agricultural production seems reasonable. The future land use projection therefore assumes that farmers respond to future climate by optimizing their crop cultivation portfolio within the same area of land they own and or manage. If future climate means better suitability for expanding cultivation of crops already existing in the farm or for growing other crops previously not suitable then this change is assumed to happen by taking fallow land back into production or by reducing grassland within the farm.

Valuation of crop production

The estimate of economic value of crop production in the future is derived by multiplying the projection of agricultural area for 2030 and 2050 for each of the different crops for a given country and the gross production value of the corresponding crop and country from the year 2010. The valuation therefore assumes constant crop yield from 2010 into the future. Crop yield in different parts of Europe is likely to change under future climate and technology, though at present the information is not available. Furthermore, for countries where future projection indicates production of crops currently not grown in these countries or where the gross production value is not available from the FAO data, a value transfer is implemented. This is done by taking the average production value from all other countries within the EU25 for which production value for the year 2010 is available for the crop subjected to the economic valuation.

2.3 Results

2.3.1 Projection of future change in agricultural land use due to climate

Table 2 and Table 3 illustrate how future climate is likely to trigger important changes in the patterns of agricultural land use in Europe. Some countries are expected to see expansion of the production of certain crops on the one hand but shrinkage in other crops. For example, France is projected to have reduction in grape cultivation but increase in tomato production. The results also indicate that, for some crops, the climatic influence across the countries in Europe is not linear into the future. A notable example is in the case of tomatoes where it is expected to expand in all countries under the 2050 climate projection but not for 2030.

Table 2. Agricultural land use change trends due to climate change in year 2030 for selected crops

Crop	Countries with expected increase of area	Country with expected decrease of area
Wheat	Spain and Portugal	All other countries (top 5: France, Germany, Poland, Romania, UK)
Barley	France, Italy, Romania, Hungary, Belgium, Portugal, Netherlands, Bulgaria	All other countries (top 5: Spain, Germany, Denmark, UK, Finland)
Tomatoes	All other countries (top 5: France, Spain, UK, Greece, Germany)	Romania, Poland, Slovakia, Latvia, Lithuania, Estonia, Finland
Potatoes	All other countries (top 5: France, Spain, Germany, Italy, and Hungary)	Netherlands, Belgium, Portugal
Maize	UK, Spain, Poland, Lithuania, Finland, Latvia, Denmark, Estonia, Sweden, Ireland, Luxembourg	All other countries (top 5: Romania, France, Hungary, Italy, Bulgaria)
Grapes	UK, Poland, Belgium, Netherlands, Ireland, Denmark, Sweden, Lituania, Latvia, Estonia, Finland	All other countries (top 5: Spain, Italy, France, Portugal, Romania)
Apples	All other countries (top 5: Finland, Spain, France, Germany, Romania)	Netherlands

Table 3. Agricultural land use change trends due to climate change in year 2050 for selected crops

Crop	Countries with expected increase of area	Country with expected decrease of area
Wheat	Spain and Portugal	All other countries (top 5: France, Germany, UK, Poland, Romania)
Barley	Romania, Hungary, Italy, France, Poland, Bulgaria, Slovakia, Portugal, Netherlands, Belgium, Austria, Slovenia	All other countries(top 5: Spain, UK, Denmark, Germany, Finland)
Tomatoes	All countries (top 5: Spain, France, Portugal, Italy, Germany))	None
Potatoes	France, Czech Republic, Germany, Bulgaria, Slovakia, Austria, Lithuania, Hungary, Italy, Estonia, Sweden, Luxembourg	All other countries (top 5: Netherlands, Belgium, Romania, Poland, UK)
Maize	UK, Poland, Lithuania, Denmark, Latvia, Germany, Ireland, Sweden, Netherlands, Estonia, Finland, Luxembourg	All other countries(top 5: Romania, France, Hungary, Italy, Bulgaria)
Grapes	All other countries (top 5: Poland, Germany, Romania, UK, Hungary)	Spain, Italy, Portugal, Greece, France, Slovenia, Luxembourg
Apples	All other countries (top 5: France, Romania, Spain, Bulgaria, Italy)	Poland, Netherlands, Slovenia, Belgium, Estonia

2.3.2 Projection of future crop production under future climate

The present model results show that future climate will potentially bring net gain for all 25 countries included in the assessment (Figure 2), all else being equal. Spain, France, Germany, Italy, UK, Poland, and Romania are among the countries likely to see significant benefit. Overall, for the year 2030, the total estimate of economic value of crop production in the EU25 is around 252.2 billion Euros; 118% increase from 2010 production. For the year 2050, the estimate is at around 286.5 billion Euros; 148% increase from 2010 production. Table 4 summarizes the magnitude of gains and losses in the total value of crop production due to land use change under future climate relative to the baseline (2010). The total value of some crops (tomatoes and other vegetables) is expected to consistently increase in both 2030 and 2050 while it is likely to reduce for other crops (e.g. wheat and barley). There are other cases where positive change is expected in 2030 but the opposite for 2050 and vice versa (e.g. potatoes and citrus). Moreover, it is interesting to note that the total production value of grape is expected to decrease in the future. This suggests that the northward shift to grape cultivation is not large enough to compensate the shrinkage of production in the south.

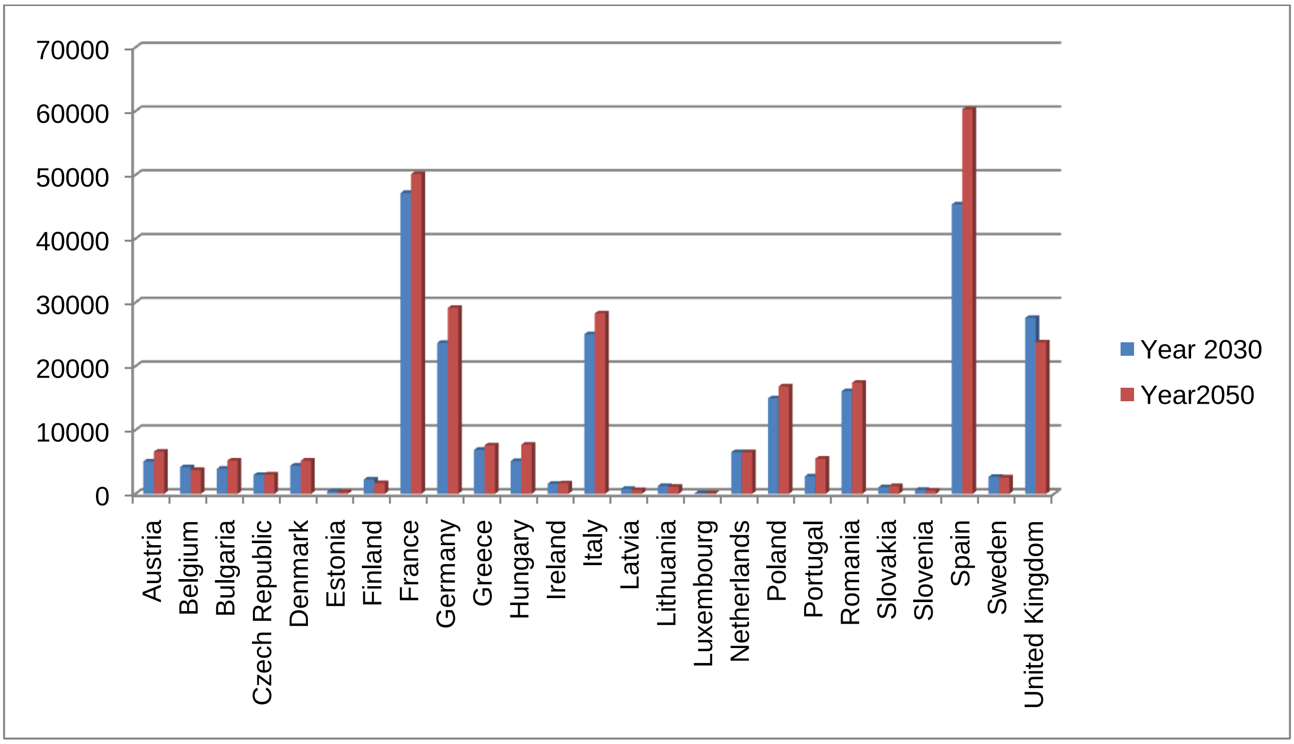

Figure 2. Estimated total value of crop production (in million Euros) with climate driven agricultural land use change

Table 4. Percent change in total value of crop production in 2030 and 2050 (relative to 2010 values) due to land use change under future climate

Crops	Year 2030	Year 2050
Wheat	-64	-54
Barley	-17	-18
Rye	94	-19
Oats	246	85
Other Cereals	-16	-38
Apples	267	185
Citrus	-16	495
Other Fruits	88	165
Grapes	-46	-16
Maize	-21	-14
Rapeseed	-73	-79
Sunflower	-84	-87
Soya	-84	-91
Other oil seeds	754	340
Olives	-18	47
Other Crops	1662	1467
Potatoes	74	-10
Sugar beet	-64	-58
Tomatoes	401	839
Other Vegetables	154	196
Rice Paddy	-76	63

2.4 Results for crops

2.4.1 Ozone damage prior to adjustment for climate

Results are shown in Table 5 for each of the crops for all countries considered, and Table 6 disaggregated to country. Overall, the reduction in ozone levels over the period 2000 to 2050 MFR suggests a potential reduction in annual damage of €3.52 billion. A substantial part of this improvement has already been achieved: the improvement from 2010 to 2050 MFR falls to €2.02 billion.

Results for the EU27 (EU excluding Cyprus) with Norway and Switzerland are shown in Table 7[3]. These results account for between 74% and 78% of the total for the longer list of European countries. The crop for which the largest damage is estimated is wheat, at over 30% of the total: no other crop provides more than 10% of the total damage. This dominance of wheat is to be expected given that wheat is widely grown and sensitive. The total damage from crops for which POD functions are available (wheat, potato and tomato) is 40%.

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[3] This grouping of countries was originally selected for comparison against results from ICP Vegetation (2011).

Table 5. Crop loss by crop in 2010 and 2030 under the V5_ECLAIRE scenarios for all Europe excluding Cyprus, Turkey (€million/year).

	production at ambient ozone	**production at zero ozone**	**CLE**	**CLE**	**CLE**	**BIO75 i77**	**MFR**	**CLE**	**BIO75 i78**	**MFR**
	2010	**2010**	**2000**	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Wheat	28,344	32,129	3,785	3,330	2,861	2,828	2,730	2,835	2,801	2,704
Potatoes	16,198	16,862	665	595	521	516	500	518	513	497
Grapes	13,643	14,144	502	425	356	350	336	353	346	332
Maize	10,721	11,535	814	717	602	594	570	597	588	565
Olives	9,119	9,928	809	686	586	577	554	582	570	550
Barley	7,787	8,096	309	271	234	231	223	232	229	221
Tomatoes	7,151	7,751	600	518	444	437	421	441	433	418
Rapeseed	5,776	6,255	479	417	351	347	333	347	343	328
Sugar beet	5,766	6,227	461	404	345	341	329	342	338	326
Apples	5,329	5,524	196	171	144	142	136	142	140	135
Sunflower seed	4,901	5,058	157	144	127	126	122	126	125	122
Mushrooms	2,774	2,774	-	-	-	-	-	-	-	-
Peaches, nectarines	2,063	2,139	75	64	54	53	51	53	52	50
Vegetables, fresh nes	1,859	1,924	65	57	49	48	47	49	48	46
Strawberries	1,761	1,772	11	10	9	8	8	8	8	8
Carrots and turnips	1,746	2,037	290	256	222	219	212	220	218	210
Onions, dry	1,623	1,903	279	247	216	213	206	214	212	205
Triticale	1,522	1,578	57	50	42	41	40	41	41	39
Plums and sloes	1,456	1,707	251	223	187	185	177	186	183	176
Cabbages, brassicas	1,426	1,473	46	42	37	36	35	36	36	35
Lettuce and chicory	1,290	1,487	197	166	139	137	131	138	135	130
Oats	1,213	1,213	-	-	-	-	-	-	-	-
Green chillies, peppers	1,205	1,245	40	35	30	29	28	29	29	28
Soybeans	1,171	1,324	154	140	122	120	117	121	120	117
Oranges	1,141	1,397	255	215	182	179	171	181	177	170
Rice, paddy	1,072	1,140	69	59	51	50	48	51	50	48
Pears	1,050	1,088	38	33	28	28	26	28	27	26
Rye	1,028	1,028	-	-	-	-	-	-	-	-
Almonds, with shell	983	1,015	32	27	23	23	22	23	22	22
Cucumbers, gherkins	938	968	30	27	24	23	23	23	23	23
Cherries	852	882	30	26	22	22	21	22	22	21
Leeks, alliaceous veg	719	745	26	22	19	19	18	19	19	18
Tangerines, etc	714	736	22	19	16	16	15	16	16	15
Raspberries	685	706	21	20	17	17	16	17	17	16
Peas, dry	656	807	151	133	116	115	112	115	114	111
Watermelons	517	566	49	44	38	38	36	38	37	36
Currants	512	528	16	15	13	13	12	13	13	12
Cauliflowers, broccoli	499	499	-	-	-	-	-	-	-	-
Grain, mixed	495	495	-	-	-	-	-	-	-	-
Kiwi fruit	475	495	20	17	14	14	13	14	13	13
Peas, green	474	593	119	102	86	85	81	85	84	81
Other crops	10,125	10,928	802	694	589	581	558	584	575	553
Total	**158,780**	**170,702**	**11,922**	**10,421**	**8,915**	**8,801**	**8,481**	**8,839**	**8,716**	**8,404**
Benefits						**114**	**434**		**123**	**435**

Table 6. Crop loss by country for each scenario (€million/year).

	production at ambient ozone	**production at zero ozone**	**CLE**	**CLE**	**CLE**	**BIO75 i77**	**MFR**	**CLE**	**BIO75 i78**	**MFR**
	2010	**2010**	**2000**	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Albania	598	628	31	28	24	24	23	24	24	23
Austria	1,615	1,742	127	110	86	85	80	84	82	78
Belarus	3,222	3,424	202	189	168	167	163	168	167	163
Belgium	2,324	2,492	168	143	125	124	119	124	123	117
Bosnia and Herzegovina	567	601	34	31	25	24	23	25	24	23
Bulgaria	2,114	2,280	166	152	125	124	119	124	122	117
Croatia	845	919	74	65	53	51	48	52	51	48
Czech Republic	1,581	1,743	162	141	113	111	105	110	108	103
Denmark	1,682	1,831	149	129	112	111	107	112	111	107
Estonia	162	174	12	11	10	10	9	10	10	9
Finland	582	607	25	23	20	20	19	20	20	19
France	19,220	21,036	1,816	1,528	1,262	1,247	1,192	1,247	1,231	1,178
Germany	11,762	12,829	1,067	912	756	743	711	744	731	697
Greece	4,930	5,287	357	318	272	269	260	271	268	260
Hungary	2,963	3,234	271	241	195	192	182	192	188	179
Ireland	463	476	13	11	10	10	9	10	10	9
Italy	18,757	20,476	1,719	1,410	1,151	1,126	1,073	1,143	1,111	1,061
Latvia	361	391	30	28	25	24	24	24	24	24
Lithuania	663	722	59	55	47	47	46	47	47	45
Luxembourg	37	40	3	3	2	2	2	2	2	2
Malta	31	34	3	3	2	2	2	2	2	2
Montenegro	96	101	5	5	4	4	4	4	4	4
Netherlands	3,391	3,625	233	200	178	176	169	177	175	167
Norway	248	255	7	6	6	6	5	6	6	6
Poland	8,845	9,462	617	556	464	458	439	456	451	431
Portugal	2,115	2,242	127	111	100	99	96	100	99	96
Republic of Moldova	1,027	1,093	66	62	55	54	53	55	55	53
Romania	5,401	5,838	438	398	337	331	317	333	327	313
Russian Federation	18,374	19,487	1,113	1,052	987	984	974	982	979	969
Serbia	2,894	3,109	215	199	160	158	151	159	156	150
Slovakia	633	694	61	54	44	43	41	43	42	40
Slovenia	243	260	17	15	11	11	10	11	11	10
Spain	19,319	20,349	1,030	879	776	768	737	768	756	731
Sweden	923	985	61	54	47	46	45	47	47	45
Switzerland	559	587	28	23	18	17	17	17	17	16
The former Yugoslav Republic of Macedonia	602	629	26	24	20	19	19	19	19	18
Ukraine	13,843	14,780	938	878	794	790	776	797	793	778
United Kingdom	5,786	6,235	448	378	331	326	313	328	325	311
Total	**158,780**	**170,702**	**11,922**	**10,421**	**8,915**	**8,801**	**8,481**	**8,839**	**8,716**	**8,404**
Benefits						**114**	**434**		**123**	**435**

Table 7. Crop loss by crop in 2010 and 2030 under the MTFR scenario in the EU25 as defined in Section 2.2.2 (€million/year)

	production at ambient ozone	production at zero ozone	CLE	CLE	CLE	BIO75 i77	MFR	CLE	BIO75 i78	MFR
	2010	**2010**	**2000**	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Wheat	19,463	22,039	2,795	2,402	2,009	1,980	1,895	1,984	1,955	1,870
Potatoes	8,709	8,948	384	332	282	278	266	278	275	263
Grapes	12,595	12,884	464	391	327	321	307	323	317	304
Maize	7,493	7,796	582	502	416	409	391	411	403	386
Olives	9,059	9,834	802	679	581	572	549	576	565	545
Barley	5,726	5,864	232	200	168	166	159	166	164	157
Tomatoes	5,552	6,005	487	413	349	343	328	346	339	325
Rapeseed	5,135	5,539	432	373	311	307	294	307	303	290
Sugar beet	4,079	4,323	342	293	245	241	231	242	238	228
Apples	4,154	4,190	157	134	112	110	105	110	108	104
Sunflower seed	1,734	1,779	63	55	46	45	43	45	45	43
Mushrooms	2,718	2,701	-	-	-	-	-	-	-	-
Peaches, nectarines	1,982	2,050	73	61	52	51	49	51	50	48
Vegetables, fresh nes	1,243	1,274	47	40	34	33	32	33	33	31
Strawberries	1,363	1,349	9	8	7	6	6	7	6	6
Carrots and turnips	1,184	1,364	207	178	151	149	143	150	148	141
Onions, dry	1,064	1,253	195	169	144	142	136	143	141	135
Triticale	1,321	1,359	50	44	36	36	34	36	35	34
Plums and sloes	892	1,027	161	140	117	115	110	116	114	109
Cabbages, brassicas	692	703	25	22	18	18	17	18	18	17
Lettuce and chicory	1,276	1,429	191	161	135	133	127	134	131	126
Oats	781	745	-	-	-	-	-	-	-	-
Green chillies, peppers	942	966	32	27	23	23	22	23	23	22
Soybeans	300	307	45	38	31	31	29	31	30	29
Oranges	1,139	1,393	255	215	182	178	171	180	176	170
Rice, paddy	765	819	54	45	38	37	36	38	37	35
Pears	922	937	34	29	24	24	23	24	24	23
Rye	741	736	-	-	-	-	-	-	-	-
Almonds, with shell	979	1,010	32	27	23	23	22	23	22	21
Cucumbers, gherkins	481	490	16	14	12	12	11	12	12	11
Cherries	622	629	23	20	16	16	15	16	16	15
Leeks, alliaceous veg	703	711	25	22	18	18	17	18	18	17
Tangerines, etc	712	722	22	18	16	16	15	16	15	15
Raspberries	265	265	9	8	7	7	7	7	7	6
Peas, dry	355	443	92	78	65	64	62	64	64	61
Watermelons	267	291	28	24	20	20	19	20	20	19
Currants	231	239	9	8	6	6	6	6	6	6
Cauliflowers, broccoli	491	484	-	-	-	-	-	-	-	-
Grain, mixed	492	492	-	-	-	-	-	-	-	-
Kiwi fruit	475	495	20	17	14	14	13	14	13	13
Peas, green	433	539	110	93	79	77	74	78	77	73
Other crops	8,031	8,627	679	579	487	479	459	482	473	454
100Total	**117,558**	**125,050**	**9,179**	**7,858**	**6,601**	**6,501**	**6,223**	**6,529**	**6,420**	**6,151**
Benefits						**100**	**378**		**109**	**378**

2.4.2 Ozone damage accounting for climate induced changes in crop production

Considering the total impacts for the entire EU 25 countries, the largest share of economic loss due to ozone in the future appears to be associated with tomatoes and the category ‘other crops’. This is in contrast with the baseline situation (2010) where wheat production is most affected.

Overall for the year 2030, taking into account the changes in area of crop production across the EU 25 countries, the estimated total crop loss due to ozone under Current Legislation (CLE) scenario is around €8.9 billion (increased from €6.6 billion without climate adjustment). Implementing the Maximum Feasible Reduction (MFR) can potentially reduce the loss by around €500 million (increased from €380 million without climate adjustment). For the year 2050, the estimated loss under CLE amounts to approximately €11.8 billion (€6.5 billion without adjustment). A reduction in total crop loss of around €700 million is to be expected as a result of implementing MFR (€370 million without adjustment). As the magnitude of crop production and ozone pollution vary across countries so does the expected benefit from implementing MFR (Figure 3). In absolute terms, the largest benefits are to be shared by France, Italy, Spain and Germany. In general, the estimated avoided loss for 2050 is higher than 2030 except for UK, Belgium, Finland, Ireland, Latvia, and Estonia where the opposite is noticeable.

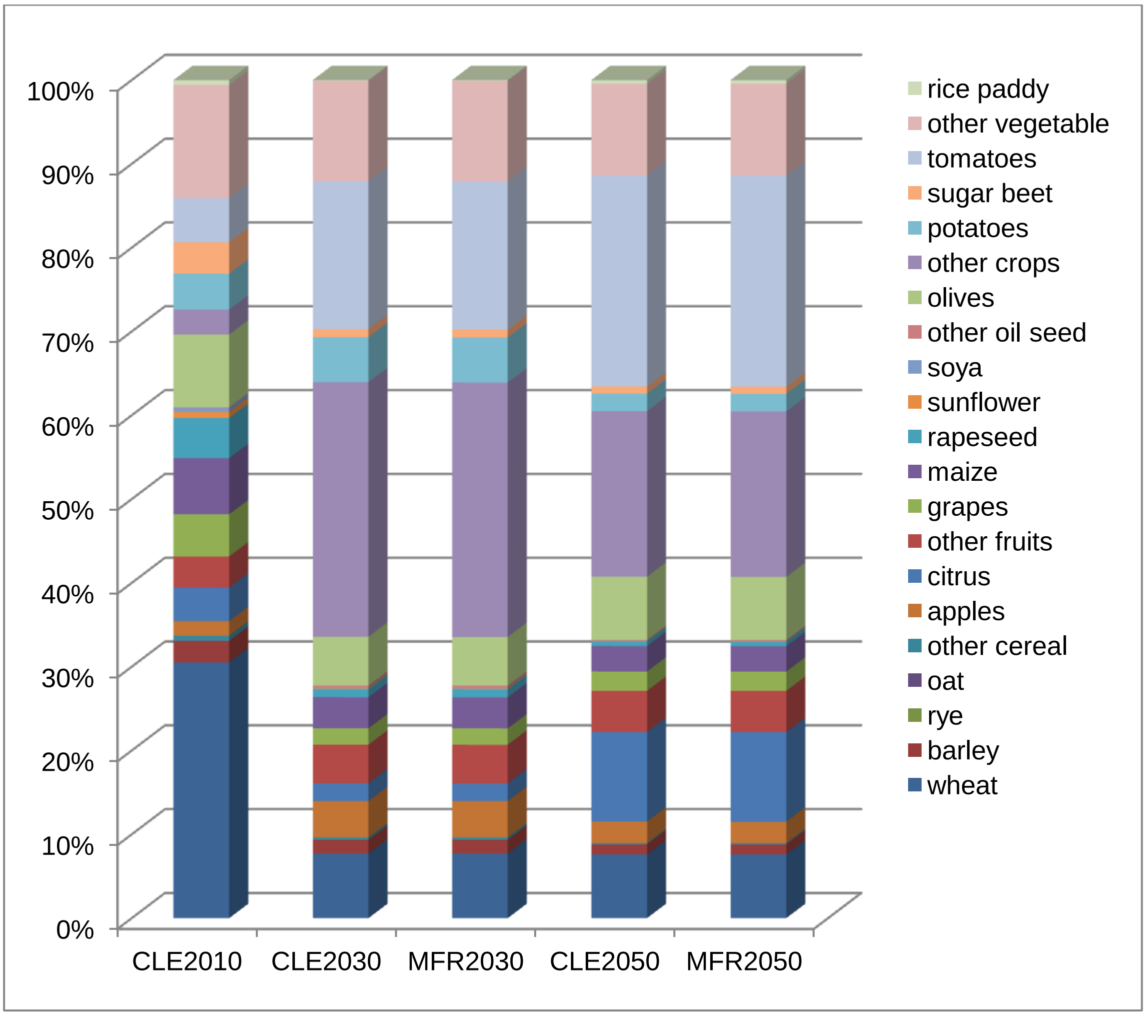

Figure 3. Distribution of economic impacts of ozone on different crops under different scenarios

The differences in damage estimates for each country for the cases with and without climate adjustment for 2030 and 2050 are demonstrated in Figure 4 and Figure 5 showing the benefits estimated to be gained from moving from the Current Legislation scenario to Maximum Feasible Reduction. In almost all cases, the climate adjusted figures are larger

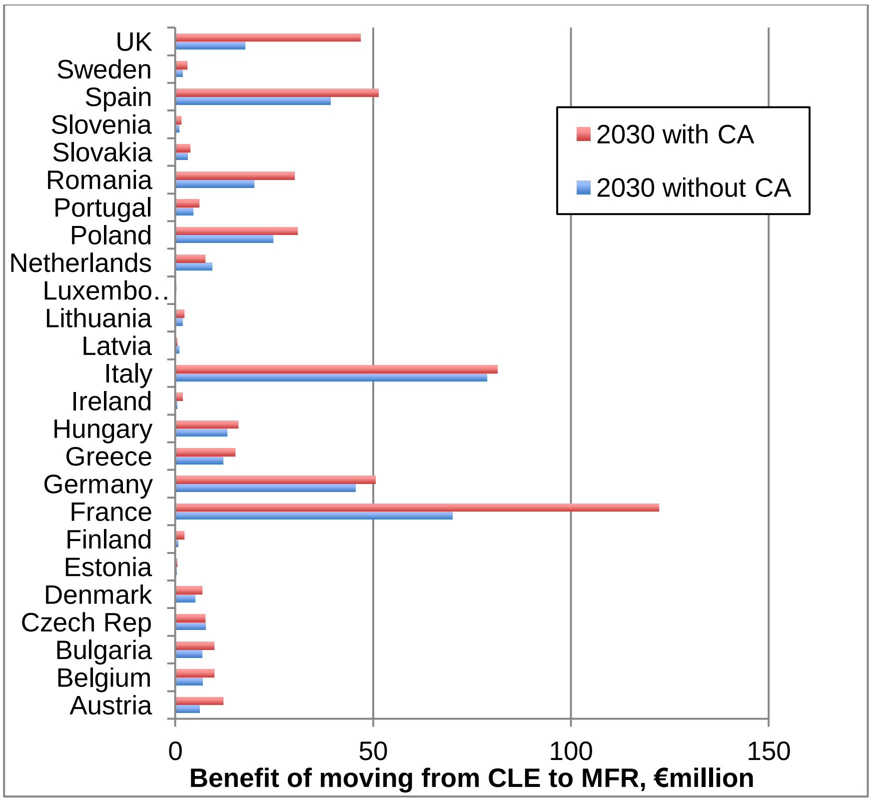

Figure 4. Avoided loss due to ozone in 2030 by implementing MFR (relative to CLE) in million Euros, with and without climate adjustment

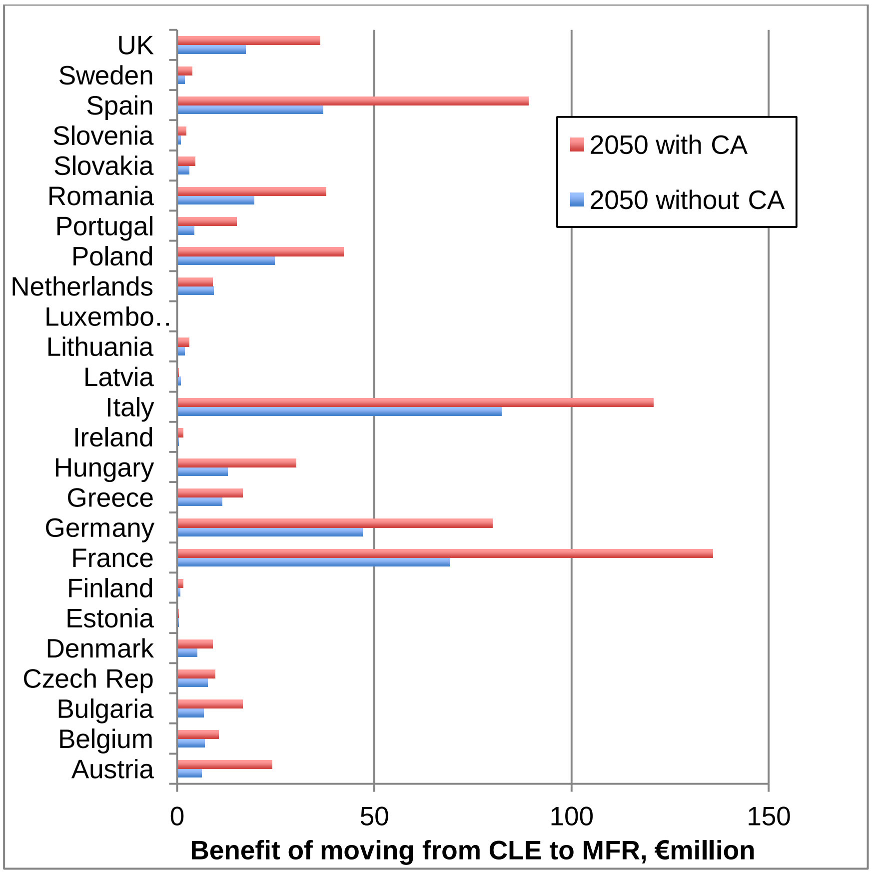

Figure 5. Avoided loss due to ozone in 2050 by implementing MFR (relative to CLE) in million Euros, with and without climate adjustment

2.5 Discussion

The results presented here support earlier estimates of ozone damage to crops by indicating that total damage is in the order of several billion euro per year (e.g. ICP Vegetation, 2011). At the same time, it extends earlier work in two important ways, first by accounting for all European crops, and second by considering the possible consequences of climate on European crop production.

There is a growing literature on the importance of future climate scenarios on agricultural production in Europe (Nainggolan et al., 2014). With respect to the current analysis a number of caveats may be noted. First, it is important to highlight that future changes in agricultural land use in the present model are driven only by climate factors, specifically temperature and precipitation. The present model does not take into account other important drivers such as how the crop market price evolves in the future, the cost of shifting from one land use to another especially in cases where substantial technological investment is necessary, etc. Nor does the present model take into account the implication of extreme events as another important dimension of climate change. Research to develop a more robust model and hence a more realistic future projection of climate driven agricultural land use change is currently on-going under the NORDSTAR and BASE projects. Nevertheless, despite the caveats mentioned, the results demonstrate that it is important to consider how future climate is likely to induce important agricultural land use shifts that will have strong implications for future agricultural production.

Despite the advances made here, the analysis could be improved to account for the following:

1. Interactions between air pollution and insect pests. Whilst it is some time since this subject was investigated in any depth, results from studies by Riemer and Whittaker (1989), Warrington (1989), Houlden et al (1990) and others indicated that the interactions could significantly increase damage. Unfortunately, no response functions are available to account for these effects in the present analysis. In any case, it would be necessary to undertake further original field research to assess the problem under modern farm management conditions.
2. The analysis does not quantify impacts of ozone production on grass yield, and then on the production of farm animals and associated products (particularly milk). Together, these account for about half of European agricultural production, and so this issue deserves further investigation.
3. The analysis does not account for total loss of crop under localized conditions where high ozone levels occur at periods when plants are most sensitive. The effect on European production of such episodes is likely to be small, given that they tend to be so localized and appear to be infrequent. However, the effects on individual farmers may be substantial. More widespread use of the ICP Vegetation mobile phone app for reporting ozone injury would greatly help in understanding how widespread this issue is.
4. The projections of damage under a changing climate do not account for changes in the price of crops in response to changes in production.

On the final point, the change in production associated with changes in ozone levels seems less problematic. Although total damage is estimated in the region of €6 to €12 billion/year, the potential for reducing ozone levels is rather low, with the result that the benefits of policy changes are likely to be in the order of €400 to €800 million/year.

It is debatable which set of estimates should be preferred – the set that includes estimates with climate adjustment or without. There clearly will be some adaptation to a changing climate, but whether this will go as far as indicated here is uncertain. It is noted from Table 4 that some crops are forecast to have very substantial increases in production, by more than an order of magnitude, raising questions of whether or not there is sufficient demand for these changes, and whether price signals to growers would remain strong enough for crop changes to occur on the scale suggested: increased production of a crop will tend to reduce its price (though perhaps not significantly on a global scale) and reduced production will tend to increase price. With this in mind, it seems appropriate to retain the climate unadjusted – climate adjusted range for the final results.

3 Forest damage assessment

3.1 General approach for forest impact assessment

The general approach used here for quantification of damage to forests is similar to that used above for crop impacts. Response functions are again quantified using phytotoxic ozone dose as the metric of pollutant exposure, and costs of changes in production are again assessed using FAO data.

There are several different types of impact that may be linked to reduced forest growth in response to ozone exposure:
- Lost production of timber for manufacture of wood products
- Lost production of timber for manufacture of paper and pulp
- Lost production of firewood
- Reduced carbon sequestration

Effects on biodiversity are addressed separately in the next chapter.

Given that many forests grow in areas that were historically low in nitrogen, there is an expectation that additional nitrogen deposition would increase growth (e.g. Follet, 2001). However, this issue has been discussed extensively in ECLAIRE, and there is some agreement that past levels of N deposition have been sufficiently high to negate much of the anticipated benefit. This is reflected by other observations in the literature. For example, Nadelhoffer et al (1999) concluded that increased nitrogen deposition was unlikely to contribute significantly to increased carbon sequestration in temperate forests. Similarly, McCarl et al (2001) discussed different agriculture and forest management options to facilitate carbon sequestration in one shape or the other (inter alia afforestation & liquid slurry management are included, but concluded that there was limited potential due to saturation. Sedjo (2001) reviewed the prerequisites for forest carbon sequestration and concluded it to be a fairly low cost climate change abatement option, but with the potential for leakage if performed in large scale. Including the benefit in the case whilst ignoring negative externalities would clearly bias results. For these reasons, no account has been taken of N deposition in this Chapter. However, if were to be included, the approach to quantification would be very similar to that demonstrated below for ozone effects.

3.2 Methods for forest impact assessment

3.2.1 Basic analysis

Analysis proceeds through the following steps (similar but not identical to those adopted for crop impact assessment above):
Step 1: Obtain forest production data as economic value of production, and in terms of carbon sequestration
Step 2: Convert economic data from international $ to euro, define values for carbon
Step 3: Define response functions
Step 4: Define geographic resolution
Step 5: Obtain ozone data
Step 6: Apply response functions and calculate impacts
Step 7: Valuation, including consideration of forest management on production of traded material

Each step is described below.

Step 1: Obtain forest production data
Forest production data for 2012, and associated data on the gross value added of forestry and logging activity (expressed in €2005 for consistency with other results), was taken from Eurostat (2015) and is shown in Table 8. Data have been checked for consistency over a longer time series, to 2006, for countries where information was available, revealing extraction rates and prices to have been reasonably stable over the period.

Table 8. Summary data on forest production for 2012. Source: Eurostat.

	Roundwood production (thousand m³)	Gross value added of the forestry and logging activity (million €,2005)	Value per m³
Austria	18,021	1,002	56
Bulgaria	6,092	162	27
Cyprus	11	1	135
Czech Republic	15,061	627	42
Finland	49,967	2,264	45
France	52,371	2,206	42
Germany	52,338	2,440	47
Greece	1,196	41	34
Hungary	5,244	134	26
Italy	8,618	298	35
Latvia	12,833	614	48
Lithuania	5,870	85	14
Luxembourg	261	19	74
Malta	0	0	
Netherlands	1,107	37	33
Norway	10,572	410	39
Poland	37,045	956	26
Portugal	10,184	612	60
Romania	16,088	451	28
Slovakia	8,202	263	32
Slovenia	3,341	189	57
Spain	14,528	621	43
Sweden	69,499	3,276	47
Switzerland	4,466	212	48
United Kingdom	10,120	364	36
Total/average	**397,996**	**17,285**	**43**

Gamfeldt et al (2013) present how tree species richness in forests is positively correlated with most ecosystem services including soil carbon sequestration. Soil carbon sequestration (storage) was 11 % higher in five-species forests than in one-species forests. Also tree biomass production was higher in five-species forests than in one-species forests. Nabuurs et al (2013) present three signs that European forests are beginning to reach carbon saturation. First they observe a slow-down in stem volume increment. Second, they observe a smaller net forestation in Europe than earlier years. Thirdly, they notice that disturbances to forest production and carbon uptake are increasing in frequency (winds, beetles, fire etc.). In addition, the damages done by these disturbances become relatively large since many forests are now quite old and contain large pools of carbon. Adapted policies are needed.

Subramanian et al (2015) found that current ozone levels in Sweden lead to a loss in Net Primary Production (NPP) of 4.3-15.3% for conifers and 1.4-4.3% for birch. Climate change was not shown to have impact in this study.

Annual carbon stock increments were obtained from Patrick Bueker, SEI/University of York, from Component 3 of ECLAIRE.

Step 2: Provide carbon price

Stavins and Richards (2005) present a US review of costs for carbon sequestration by forest management practices. From their literature review they conclude that 300 Mton carbon could be sequestered in the US for a cost of \$7.5 – \$ 22.5 / ton CO_2eq. The price increased to \$ 26 / ton CO_2eq for a 500 Mt carbon potential. These values are based on an extensive synthesis of results from 11 studies. The carbon sequestration supply function is relatively linear.

Kettunen et al (2010) present Nordic perspectives of the TEEB (The Economics of Ecosystems and Biodiversity) report and values for fishing as well as total carbon sequestration in soils and forests in Sweden. But no specific values for carbon sequestration per tonne of C or CO_2 are given. They cite

Gren and Svensson (2004) that calculate the annual carbon sequestration of forests in Sweden to be worth 29-46 billion SEK2001 (€3.3-5.2 billion). These numbers are based on a consumption value of €40-65 / ton CO_2 (abatement cost in energy sector) and an investment cost of €1377-2169 / ton CO_2 for the stock change. In Finland, another study presented results on carbon sequestration in forest trees to be worth €1,876 million, and the value of the change in mineral soil carbon stock to be worth €136 million. These numbers are based on the Finnish carbon tax of €17.1 / ton CO_2 and a material decay discount factor of 0.74 to derive a value of €17.3/m^3 forest trees (Matero and Saastamoinen, 2007).

The United States Government Interagency working group on social cost of carbon (2013) has updated its 2010 estimates for the Social Cost of Carbon. The importance of having year-specific CO_2 cost estimates is highlighted, which in turn makes their CO_2 valuation scenario-specific. If translated to our discussion on carbon sequestration: the higher the abatement efforts already made, the lower the value of additional carbon sequestration. Revesz et al (2014) comment on the Interagency working group's report and stress the need for further integration and development. Social costs of $37 / ton CO_2 if emitted today and $43 / ton CO_2 if emitted in 2020 are stated (and discussed as low estimates).

From this it is clear that the valuation of climate change impacts is subject to a range of uncertainties that have led in the past to large ranges in estimates, according to the effects considered and the approach adopted. The European Environment Agency (2014) adopts a range of €9.5 to €38.1/t CO_2 based on recent modelled carbon price forecasts under the EU's Emission Trading System (EU-ETS) performed for the European Commission to support the proposal for a 2030 climate and energy policy framework (European Commission, 2014). This approach provides a reflection of the costs associated with decreasing CO_2 emissions in the EU over time in line with the required reduction necessary to meet the current policy objective of limiting future limit average global surface temperature increase to two-degrees. The range of values (in 2005€) is:

- A lower value of €9.5 per tonne CO_2 reflecting the modelled ETS price in 2020 based on a reference scenario of implementation of current legislation
- A higher value of €38.1 per tonne CO_2 reflecting the projected carbon price in 2030 in a central scenario of 40% domestic GHG emission reduction by 2030 compared to 1990 (European Commission, 2014).

Dietz and Stern (2014) provide a range for the carbon price from analysis using the DICE model, $32-103/t$CO_2$ (2012 prices, or €23-74/t in 2005 prices) in 2015 and $82-260/t$CO_2$ (€54-187/t) 'within two decades'. They note that the DICE model lacks adjustment costs, so the high end of the range should be interpreted cautiously. However, they also note that they have omitted important risks in relation to the distribution of damages, which could give higher carbon prices. Considering the uncertainties involved, and the 2030-2050 timescales relevant to the ECLAIRE scenarios, a range of €38.1 to €187/t CO_2 is adopted for the analysis below for the 2030 and 2050 scenarios. For the scenarios for 2000 to 2010, a range of €9.5 to €74/t CO_2 is used.

Step 3: Define response functions

ECLAIRE deliverable 12 has provided novel response functions for a variety of forest trees (Bueker and Emberson, 2014). These have been updated, with revised versions shown in Table 9 (Patrick Bueker, SEI, personal communication).

Table 9. POD1 response functions for forest trees, showing % change in net annual increment per unit POD1.

	Default	R^2
Norway spruce	y = -0.0054x + 1.0002	0.56
Birch & Beech	y = -0.0094x + 0.9459	0.61
Oak	y = -0.0057x + 1.0167	0.75
Aleppo Pine	y = -0.0050x + 0.9998	0.64
Quercus ilex	y = -0.0041x + 0.9988	0.69
Aleppo pine and Quercus ilex	y = -0.0047x + 1.001	0.64
Broadleaf deciduous forest	y = -0.0066x + 0.9377	0.48
Coniferous forest	y = -0.0052x + 0.999	0.69
	Min	**R^2**
Norway spruce	y = -0.0051x + 1.0003	0.55
Birch & Beech	y = -0.0091x + 0.9463	0.61
Oak	y = -0.0052x + 1.0142	0.75
Aleppo Pine	y = -0.0046x + 0.9989	0.64
Quercus ilex	y = -0.0038x + 0.9989	0.69
Aleppo pine and Quercus ilex	y = -0.0043x + 1.0003	0.64
Broadleaf deciduous forest	y = -0.0062x + 0.937	0.46
Coniferous forest	y = -0.0048x + 0.9988	0.69
	Max	**R^2**
Norway spruce	y = -0.0062x + 1.000	0.56
Birch & Beech	y = -0.0101x + 0.9445	0.61
Oak	y = -0.0066x + 1.0212	0.75
Aleppo Pine	y = -0.0058x + 1.0013	0.65
Quercus ilex	y = -0.0048x + 0.9987	0.69
Aleppo pine and Quercus ilex	y = -0.0055x + 1.0021	0.65
Broadleaf deciduous forest	y = -0.0075x + 0.9374	0.51
Coniferous forest	y = -0.0060x + 0.9993	0.69

It is noted that the ranges around the 'default' estimate are small. It is considered for the purpose of the present report that they are unlikely to capture the full uncertainty associated with the extrapolation of experimental data to the European scale.

Step 4: Define geographic resolution
The ozone data provided for scenario analysis in policy development for the European Commission are provided at national level only, though represent a receptor-weighted average for each country. The geographic resolution adopted here is thus the national scale.

Step 5: Obtain ozone exposure data.
Ozone data for the scenarios listed in Table 1 were provided by IIASA for the analysis (Chris Heyes, IIASA, personal communication).

Step 6: Application of the response functions.
Existing production data are of course depressed as a result of exposure to current levels of ozone. A first stage is therefore to quantify a counter-factual level of production, assuming that ozone levels (here, as POD3IAM) = 0. This is calculated for each country using the following expression, where DRF = dose response function:

$$Yield\ at\ zero\ ozone = \frac{2010\ yield}{1 - [POD1IAM \times DRF]}$$

Hence if ambient ozone in 2010 reduced forest yield by 20% (the product of POD1IAM and DRF), the yield at zero ozone would have been 25% higher than reported production.

Assuming that forest production patterns remain unchanged, the impacts of ozone in future years can then by calculated as follows:

$Impact_y = 2010\_production * POD1IAM_y * DRF$

Where the subscript *y* refers to the target year for quantification.

Unlike the case for crop damage assessment, no account has been taken here of changes in the forest species grown in different parts of Europe in response to climate change. On the timescale of interest (35 years, to 2050), it is here considered unlikely that there will be a significant change particularly in relation to harvested product (given the lifespan of forests).

Step 7: Valuation, including taking account of forest management

Data from EEA[4] show that the annual increment in forest growth exceeds the extraction of forest material to a substantial degree in most countries. Albania is a clear exception, where throughout the time period considered, fellings have exceeded growth (with a utilisation rate of 234% in 1990, 297% in 2000 and 550% in 2010). The only other cases where utilisation rate exceeds 100% are for Cyprus in 1990 and Estonia in 2000, though for 2010 utilisation rates in both countries were much lower (Estonia 51%, Cyprus 25%).

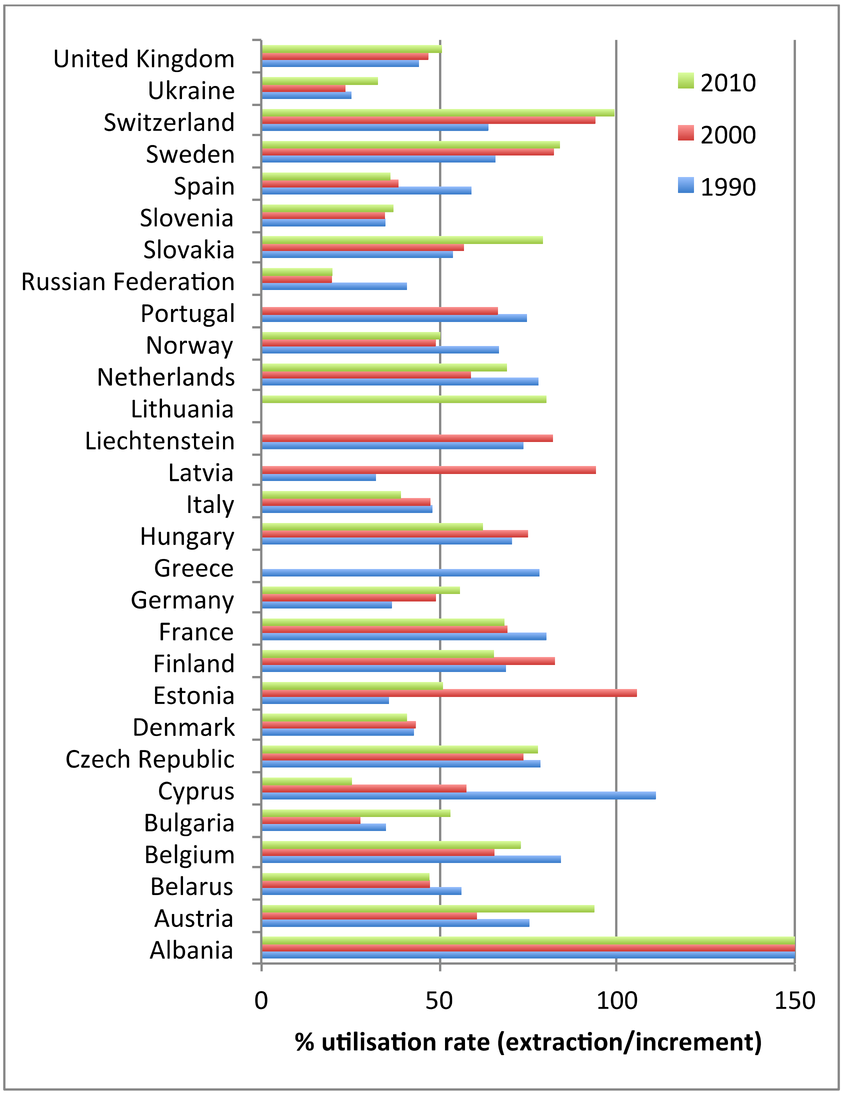

Figure 6. Utilisation rate for European forestry, expressed as annual extractions divided by annual increment. Results for Albania are truncated. Source: EEA, 2015.

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[4] http://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings/forest-growing-stock-increment-and-4

On this basis there is an argument that the European market for timber and associated forest products will not be affected by changes in growth linked to changes in ozone exposure in the future: there is already an excess level of production beyond demand. On this basis, the value of a change in production will be zero, provided that change is not substantial. However, this position is dependent on details of forest management, how much forest is used for production, and how this will change over time as demand for some wood products falls (e.g. demand for paper, if we are to move closer to a paperless society) and demand for others rises (e.g. fuel wood, in response to increased demand for biomass to displace fossil fuels). In this situation, a change in production levels could feed through to a change in the commercial value of forestry. Both positions are considered below.

3.3 Results

3.3.1 Change in exposure

Results from the dispersion modeling indicate that ozone dose will fall over time (Figure 7). Whilst the effect of this will be to increase yield, the information presented in Figure 6 on utilization rates implies that this may have little effect on the market for wood and wood products given that demand is already below annual increment for Europe.

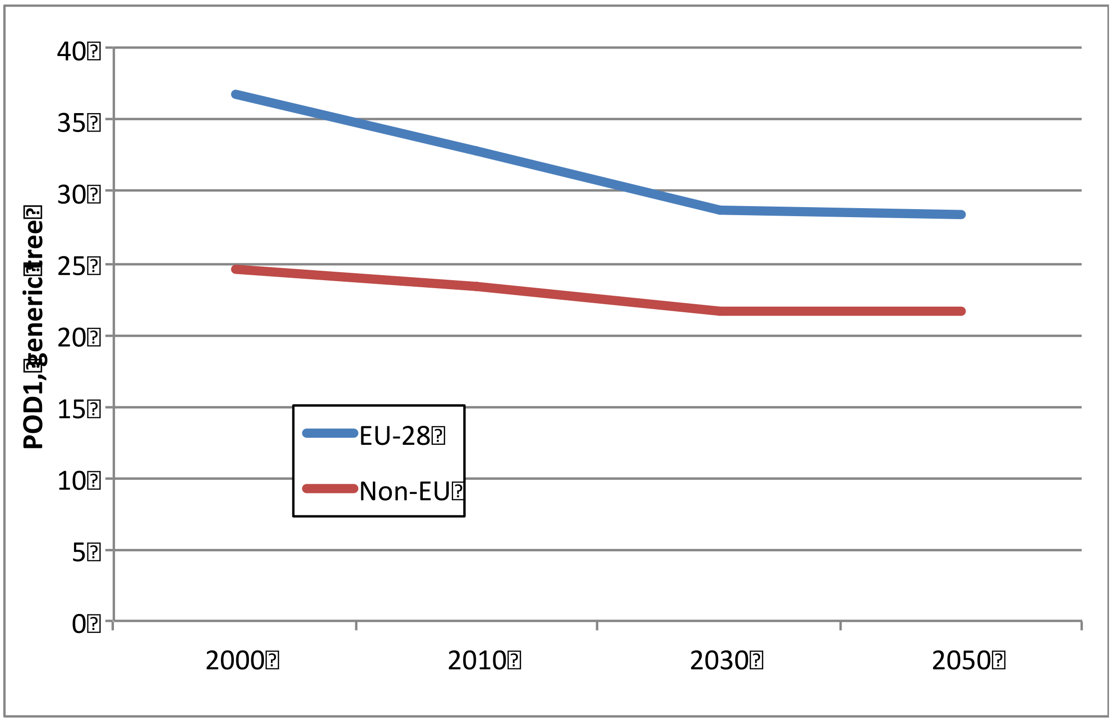

Figure 7. Ozone dose (expressed in terms of POD1 for generic tree) for the Current Legislation (CLE) scenario over time.

3.3.2 CO_2 sequestration

The reduction in CO_2 sequestration for each of the ECLAIRE scenarios is shown in Table 10. Overall, values are higher than those calculated by Bueker and Emberson (personal communication), though the scenarios used are not directly comparable. Economic values by country and scenario are shown in Table 11. The ranges account for uncertainty in both the response function and valuation. There is a step change in values from 2010 to 2030, corresponding to the use of higher values for CO_2 for the later period. The total values for the impacts of ozone on carbon sequestration are large (roughly €4 to 30 billion/year for 2030 and 2050), but the benefits from the policy scenarios are much smaller (€50 – 200 million/year for the best estimate, €300 – 1200 million/year for the upper estimate). This reflects the data on the change in exposure shown in Figure 7, above.

Table 10. Estimated reduction in carbon sequestration due to ozone exposure for the ECLAIRE scenarios (Mt CO_2eq/year) (best estimate)

Country	CLE	CLE	CLE	BIO75	MFR	CLE	BIO75	MFR
	2000	2010	2030	2030	2030	2050	2050	2050
Austria	8.32	7.38	6.21	6.12	5.88	6.12	6.03	5.79
Belgium	1.49	1.32	1.19	1.18	1.15	1.18	1.17	1.14
Bulgaria	4.23	3.93	3.39	3.35	3.25	3.35	3.32	3.22
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	5.96	5.36	4.64	4.58	4.41	4.57	4.52	4.35
Denmark	1.32	1.21	1.11	1.11	1.08	1.11	1.10	1.08
Estonia	2.21	2.07	1.90	1.89	1.85	1.90	1.89	1.85
Finland	10.47	9.84	9.11	9.08	8.92	9.12	9.10	8.92
France	26.02	22.65	19.61	19.44	18.81	19.46	19.26	18.66
Germany	31.73	28.16	25.04	24.76	23.99	24.82	24.55	23.76
Greece	0.93	0.85	0.74	0.73	0.71	0.73	0.72	0.71
Hungary	2.12	1.91	1.62	1.59	1.53	1.59	1.57	1.51
Ireland	0.68	0.64	0.60	0.60	0.59	0.60	0.60	0.59
Italy	9.57	8.08	6.79	6.67	6.43	6.75	6.59	6.36
Latvia	3.59	3.36	3.07	3.05	2.99	3.06	3.05	2.98
Lithuania	2.55	2.38	2.16	2.15	2.10	2.15	2.14	2.09
Luxembourg	0.18	0.16	0.14	0.14	0.14	0.14	0.14	0.13
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands	0.55	0.49	0.46	0.45	0.44	0.46	0.45	0.44
Poland	16.15	14.85	13.12	12.99	12.61	12.99	12.88	12.48
Portugal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Romania	9.06	8.35	7.28	7.18	6.92	7.20	7.11	6.85
Slovakia	3.16	2.88	2.47	2.44	2.35	2.43	2.40	2.31
Slovenia	2.25	1.98	1.64	1.61	1.54	1.62	1.59	1.52
Spain	10.83	9.55	8.68	8.61	8.35	8.64	8.54	8.32
Sweden	11.13	10.29	9.52	9.49	9.31	9.60	9.57	9.38
United Kingdom	4.26	3.93	3.75	3.73	3.66	3.76	3.74	3.67
Total	**168.74**	**151.60**	**134.25**	**132.96**	**129.03**	**133.36**	**132.04**	**128.12**

Table 11. Damage cost from reduced carbon sequestration in the ECLAIRE scenarios, €million/year, best estimate but with low and high estimates also in the total rows.

Country	CLE	CLE	CLE	BIO75	MFR	CLE	BIO75	MFR
	2000	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Austria	79	70	237	233	224	233	230	221
Belgium	14	13	45	45	44	45	45	43
Bulgaria	40	37	129	128	124	128	126	123
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	57	51	177	175	168	174	172	166
Denmark	13	11	42	42	41	42	42	41
Estonia	21	20	72	72	71	72	72	70
Finland	99	93	347	346	340	348	347	340
France	247	215	747	741	717	741	734	711
Germany	301	267	954	943	914	946	935	905
Greece	9	8	28	28	27	28	28	27
Hungary	20	18	62	61	58	61	60	57
Ireland	6	6	23	23	23	23	23	23
Italy	91	77	259	254	245	257	251	242
Latvia	34	32	117	116	114	117	116	114
Lithuania	24	23	82	82	80	82	82	80
Luxembourg	2	2	5	5	5	5	5	5
Malta	-	-	-	-	-	-	-	-
Netherlands	5	5	17	17	17	17	17	17
Poland	153	141	500	495	481	495	491	476
Portugal	-	-	-	-	-	-	-	-
Romania	86	79	277	274	264	274	271	261
Slovakia	30	27	94	93	89	93	92	88
Slovenia	21	19	63	61	59	62	61	58
Spain	103	91	331	328	318	329	325	317
Sweden	106	98	363	361	355	366	365	357
United Kingdom	40	37	143	142	140	143	142	140
Total (best)	**1,603**	**1,440**	**5,115**	**5,066**	**4,916**	**5,081**	**5,031**	**4,881**
Benefit (best)				**49**	**199**		**50**	**200**
Total (low)	**1,251**	**1,124**	**3,992**	**3,954**	**3,837**	**3,966**	**3,926**	**3,810**
Benefit (low)				**39**	**155**		**39**	**156**
Total (high)	**15,228**	**13,681**	**30,616**	**30,320**	**29,425**	**30,412**	**30,111**	**29,217**
Benefit (high)				**295**	**1,191**		**302**	**1,195**

3.3.3 Production values

As noted above, the surplus production of wood in Europe as indicated by the utilization rate of less than 100%, could be taken to imply that the effects of ozone (and, to be more precise, the value of future policy interventions, beyond those already legislated for, that address ozone exposure and forest production) could be zero. However, recognizing that future demands for forest production may differ to those of today, for example through the use of wood for biomass fuel to mitigate fossil CO_2 emissions, it is still appropriate to estimate the magnitude of impacts of ozone and of future possible policy-related benefits. Results are shown in Table 12. Given that this part of the analysis is based on the current value of forest production, the analysis only addresses uncertainty in the response functions used. The broad order of impacts seems consistent with that estimated for crops, bearing in mind the much higher value of crop production than forest production in Europe (roughly a factor 6 different).

Table 12. Damage cost from reduced gross added value of forest production in the ECLAIRE scenarios, €million/year, best estimate but with low and high estimates also in the total rows.

Country	CLE	CLE	CLE	BIO75	MFR	CLE	BIO75	MFR
	2000	2010	2030	2030	2030	2050	2050	2050
Austria	248	220	185	183	176	183	180	173
Belgium								
Bulgaria	40	37	32	32	31	31	31	30
Cyprus								
Czech Republic	150	135	117	115	111	115	114	109
Denmark								
Estonia								
Finland	264	248	230	229	225	230	230	225
France	520	453	392	389	376	389	385	373
Germany	559	496	441	436	423	437	432	419
Greece	9	9	7	7	7	7	7	7
Hungary	30	27	23	23	22	23	22	21
Ireland								
Italy	85	72	61	60	57	60	59	57
Latvia	112	105	96	95	93	95	95	93
Lithuania	16	15	14	14	14	14	14	13
Luxembourg	4	4	3	3	3	3	3	3
Malta								
Netherlands	8	7	7	7	6	7	7	6
Poland	207	190	168	167	162	167	165	160
Portugal								
Romania	100	92	81	79	77	80	79	76
Slovakia	62	56	48	47	46	47	47	45
Slovenia	52	46	38	37	35	37	37	35
Spain	119	105	95	95	92	95	94	91
Sweden	386	357	330	329	323	333	332	325
United Kingdom	67	62	59	59	58	59	59	58
Total (best estimate)	**3,039**	**2,736**	**2,427**	**2,405**	**2,335**	**2,413**	**2,391**	**2,321**
Benefit (best) vs CLE				**22**	**91**		**22**	**92**
Total (low)	**2,372**	**2,135**	**1,894**	**1,877**	**1,823**	**1,883**	**1,866**	**1,811**
Benefit (low) vs CLE				**17**	**71**		**17**	**72**
Total (high)	**3,706**	**3,336**	**2,960**	**2,933**	**2,848**	**2,943**	**2,915**	**2,830**
Benefit (high) vs CLE				**27**	**112**		**27**	**112**

Results are generally lower than those for carbon sequestration, because of the high values given to carbon in the later years (noting also that the lower variability between the earlier and later years shown here arises from the use of substantially higher values per tonne of CO_2 from 2030 onwards).

3.4 Discussion

Results indicate the future (post-2030) high values of forests for carbon sequestration. Whilst there are uncertainties in the analysis, the broad order of benefits possible from future policy changes leading to lower ozone exposure appears small for the gross production values, but larger for carbon sequestration. One reason for this is the utilisation rate of European forestry, though it is noted that sequestration will decline as forests age (a factor not accounted for here).

As note above, there is some consistency in the relative benefits to be gained for crops and for forests, when account is taken of differences in the respective total values of production in Europe.

It is noted that the values obtained here for carbon sequestration are roughly 50% greater than those calculated by Bueker and Emberson (personal communication). This indicates that the simplified version of the model developed in this work package could be further refined to better match the outputs of the more complex models. However, the overall impact of this on a cost-benefit analysis of European air quality strategies appears limited in most cases. The one case where it is not concerns use of the upper bound estimates of the value of carbon from 2030 onwards. In these cases, the benefits of controlling ozone could extent to around €1 billion per year.

4 Assessment of the benefits of reducing impacts on biodiversity

4.1 Methods

Following a workshop of this Work Package held at RIVM in December 2013, it was decided to investigate the use of three different approaches to the quantification of damage to natural ecosystems.

The first of these is based on available information from stated preference studies on ‘willingness to pay’ (WTP) for protection of biodiversity, drawing on the work of Christie et al and Jones et al (2013). The second is based on use of repair costs drawing on the results of Ott et al (2006), and the third on the inferred costs of environmental policies. The methods based on repair costs and inferred costs of policies are both ‘revealed preference’ approaches.

It was also decided that the work should focus on Natura 2000 areas, for which there is a legal responsibility on Member States to preserve, maintain and restore.

Each of the methods is applied here. There s a clear methodological preference from an economics perspective on the application of the stated preference data to describe WTP. However, it is accepted here that the current basis for doing this is slim, with a very limited literature available on which to base estimates of the marginal benefits of protecting biodiversity. The use of the other methods is thus intended to provide some additional insight.

4.1.1 WTP for protection of biodiversity (stated preference)

The analysis here is based on the results of the Christie et al study (2006, 2011, 2012) designed to inform the development and appraisal of the UK’s biodiversity Action Plan (UK BAP). Christie’s work provides estimates of household WTP for environmental protection, and hence reflect preference from the perspective of the general public.

Of the studies available it is considered most appropriate to the needs of the present work for several reasons, for example:

- it deals with WTP for a change in status of the ecosystems under investigation
- It recognises that different types of ecosystem will be valued differently
- It is aligned to a degree with the ecosystem services concept
- It is European.

Against this, it is a single study (albeit part of a series), investigating valuation in a single country.

The selection of the appropriate WTP estimate from Christie et al is open to debate. For the purposes of illustration, this paper takes the estimate of €10-30 per household per year adopted for analysis by Maas (2014) for presentation to the 2014 meeting of ICP Mapping and Modelling. This is representative of WTP for ‘non-charismatic’ species in the area local to one’s home (‘within own region’ as expressed by Christie et al), selected also by Jones et al as an indicator of the WTP to protect ‘biodiversity’.

There are two ways that this figure could be extrapolated to other countries (leaving aside, for the moment, the major issues of value transfer here relating to different incomes in different countries and differences in appreciation of nature between countries). The first is to assume that an average household is willing to pay €10-30 per household per year for nature protection, the second that WTP will vary according to the area of ecosystems at risk, in line with the equivalent UK valuation per unit area. Applying results per household suggested very high valuations per unit area in some countries where there was limited exceedance of the critical load over nature areas. Accordingly, a valuation of €80 to 240/ha/yr was calculated, applying the household WTP described above to the area of protected UK sites at risk. This was applied to protected sites at risk in all countries, using data generated by IIASA for the ECLAIRE scenarios out to 2050. No consideration was given to unprotected sites, recognising that the Christie et al work was performed against the background of the UK’s Biodiversity Action Plan which does not address sites that are uncategorised for protection.

Within ECLAIRE it has not proved possible to factor species richness into the analysis at the full European scale, though progress has been made in that direction by Jones et al.

It is then necessary to consider whether there is information available that would improve the process of value transfer from the UK to the whole EU. Different types of data were considered in deliverable 18.3:

- Average per capita income, reflected through GDP adjusted for purchasing power parity,
- Levels of environmental concern as indicated by Eurobarometer survey data and
- Government expenditure on environmental protection, also as an indication of societal concern.

With respect to the first option, it was noted that the data for making the adjustment are readily available. For analysis focused at the national level it may well be appropriate to make such adjustment. This is less clear at the European level, noting that similar adjustment is not made for health impacts, avoiding the dilemma of valuing individuals in different countries at different levels, even when exposed to the same pollution source. For the second option it was concluded that data were not available at a sufficient level of disaggregation to allow meaningful differentiation between Member States (or alternatively, that differences in attitude between countries were small, not warranting adjustment of values). For the third option, inconsistencies were noted between countries, and the approach was not taken further. It may become more applicable in the future in the event that consistency in reporting between countries improves. The effects of adjusting for income levels were considered in Deliverable 18.3. So far as total estimates of damage were concerned, the adjustment made little difference, given that the UK is in the middle ground of EU countries so far as per capita GDP is concerned. Effects are, naturally, greater for those countries that are well above or below the EU average, though this effect may decay over time as income differences are expected to erode between countries (OECD, 2012). Given the limited impact on overall estimates, and in the interests of simplicity, this type of adjustment is not applied to the results below.

4.1.2 Restoration costs (revealed preference)

Recognising that the omission of damage to ecosystems was a major gap in the ExternE toolset, Ott et al (2006, under the NEEDS Project) presented an approach for assessing biodiversity losses due to energy production, including effects of SO_2, NOx and NH_3 based on the use of repair costs. Ecological restoration is applied already in some regions, for example the Dutch Heathlands. The concept behind this approach is that the costs of restoration reflect societal WTP for improved protection of biodiversity. The use of repair costs has a distinct advantage over other methods in being able to utilise cost data from the real market of ecosystem restoration, though it is not without its problems.

Analysis was performed in two stages:

1. Assessment of the ‘potentially disappeared fraction’ (PDF) of species due to pollutant deposition, drawing on previous studies by Eco-indicator (1999) and Koellner (2001).
2. Valuation of estimated PDF changes using a restoration cost approach.

Ott describes the process for determination of the baseline state for a particular land-use as follows: *The PDF of vascular plant species is expressed as the relative difference between the number of species S on the reference conditions and the conditions created by the conversion, or maintained by the occupation. Basing on these data, PDF was calculated as follows:*

$$PDF = 1 - S_{use} / S_{reference}$$

where S_{use} *is the species (richness) number of an occupied or converted land use type and* $S_{reference}$ *is the average species number in the reference area type. The species number of a specific land use type is standardised for 1* m^2*. This absolute species number is transformed into a relative number using the regional species richness of the Swiss Lowlands [40 species per* m^2*] as a reference.*

PDF values are then given for a series of different CORINE land types.

For the impact assessment, modelling of the change in PDF was performed by first estimating the Probability of Occurrence (PO) for different plant species in different ecosystem types under different levels of acidification and eutrophication. The PDF is then calculated as

PDF = 1 - PO

The PDF can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavourable conditions caused by acidification and eutrophication.

Dispersion modelling to describe NOx, SO_2 and NH_3 deposition was undertaken using a Dutch model (Natuurplanner), and the changes in deposition were then translated into changes in the PDF drawing on information from Eco-indicator 99 (1999) which contains information for more than 40 types of ecosystems. For the purpose of the modelling, Ott et al considered that a species would be at significant risk (‘stressed’) if its probability of occurrence was less than a threshold of 2.5%. The number of stressed target species was counted and the results aggregated for the total natural area in the Netherlands, resulting in a percentage of threatened species caused by a specific level of deposition.

In the case of valuing biodiversity losses due to deposition of airborne emissions, the average costs of restoration of more or less natural areas (for which a very broad definition was applied: essentially any area that is not urban) to land use categories with high biodiversity were considered. Cost estimates were based on the cheapest habitat restoration choices available to bring about a significant improvement in biodiversity through the PDF concept. Using German data on restoration costs a marginal cost of 0.49 €/(PDF*m^2) was calculated. [The mix of Dutch and German data, and their extrapolation to the European scale, highlights the limited availability of information for this analysis].

Ott et al cite the following assumptions used in the calculation of external costs per kg of air pollutant for different countries:

1. The PDF change per mass of pollutant (PDF/kg deposition per m^2) as derived for the Netherlands is the same for all European countries.
2. The marginal costs of 0.49 €/(PDF*m^2) calculated for Germany need only be corrected by purchasing power (PPS) to be valid for other countries as well.
3. Degradation (a change in PDF) only takes place on natural land. According to ten Brink et al (2000), natural land encompasses all CORINE land use classes except the classes 1 (artificial areas) and 2 (agricultural areas) (for a CORINE list, see Koellner 2001).
4. The background level of acidification and eutrophication of the respective country influences the impact of additional depositions on biodiversity and hence the resulting external costs.

Ott et al then presented results in terms of external costs per unit of PDF change and per kg deposition of sulphur and nitrogen. It is understood that these results account for the fraction of natural areas within each country, and hence that the total damage per country can be estimated by multiplying the figures shown by total national deposition (see Table 15 of Ott et al). Results for NOx and NH3 are shown in Table 13. Finally, they sought to validate their results using information from available WTP studies.

Table 13. External costs per kg deposition for NOx and NH3, PPP adjusted, €/kg for 2004.

	NOx	NH_3
EU25	0.75	1.88
Austria	1.51	3.91
Belgium	0.96	2.49
Bulgaria	0.06	0.35
Croatia	0.65	1.55
Cyprus	0.01	0.08
Czech Republic	0.54	1.41
Denmark	0.40	1.13
Estonia	0.50	2.16
Finland	1.36	1.43
France	0.48	1.87
Germany	1.41	3.81
Greece	0.02	0.09
Hungary	0.40	0.92
Ireland	0.14	0.28
Italy	0.53	2.08
Latvia	0.23	1.22
Lithuania	0.21	0.66
Luxembourg	1.55	4.03
Malta	0.70	2.73
Netherlands	1.15	3.14
Poland	0.53	1.44
Portugal	0.06	0.35
Romania	0.10	0.45
Slovakia	0.79	1.80
Slovenia	1.42	3.37
Spain	0.06	0.28
Sweden	1.10	0.65
United Kingdom	0.48	0.12

There are a number of problems relating to the use of the restoration cost approach, reviewed in more detail in the Discussion to this chapter.

4.1.3 Regulatory revealed preference

This third approach takes the view that the costs of meeting critical loads in Natura 2000 areas are implied in the Birds and Habitats Directives. Continued emissions at current levels will lead to continued exceedance, and hence the requirement that Natura 2000 sites should not be allowed to deteriorate will not be met. Alongside the more local NH_3 deposition there is a need to also consider (large scale) NOx-reduction.

The valuation can be carried out by considering the costs of scenarios modelled using GAINS and the extent to which N emissions need to be reduced to meet the critical load for eutrophication. In some areas it is possible that rather small reductions in emissions may be sufficient, but in many the required emission reduction may exceed what is possible using IIASA's Maximum Feasible Reduction (MFR) scenario.

Of course, our analysis deals with the costs of environmental damage rather than the costs of abatement in each country. This should ideally be recognised in the way that inferred damage costs are attributed to each country.

As will be shown, application of all abatement measures within GAINS is insufficient to attain full compliance with critical loads. Then, the costs of additional measures need to be considered. A possibility would be to control livestock farming in affected areas, and some estimate of the cost of this can be made from data on the annual value of livestock production.

Again, the limitations of the approach are reviewed in the discussion to this chapter.

4.2 Results

The extent of the problem of critical loads exceedance for nutrient nitrogen is shown in Figure 8. Many countries have very high levels of exceedance (24 with >50% area subject to exceedance in 2000, 13 with >50% area exceedance even under MFR in 2050).

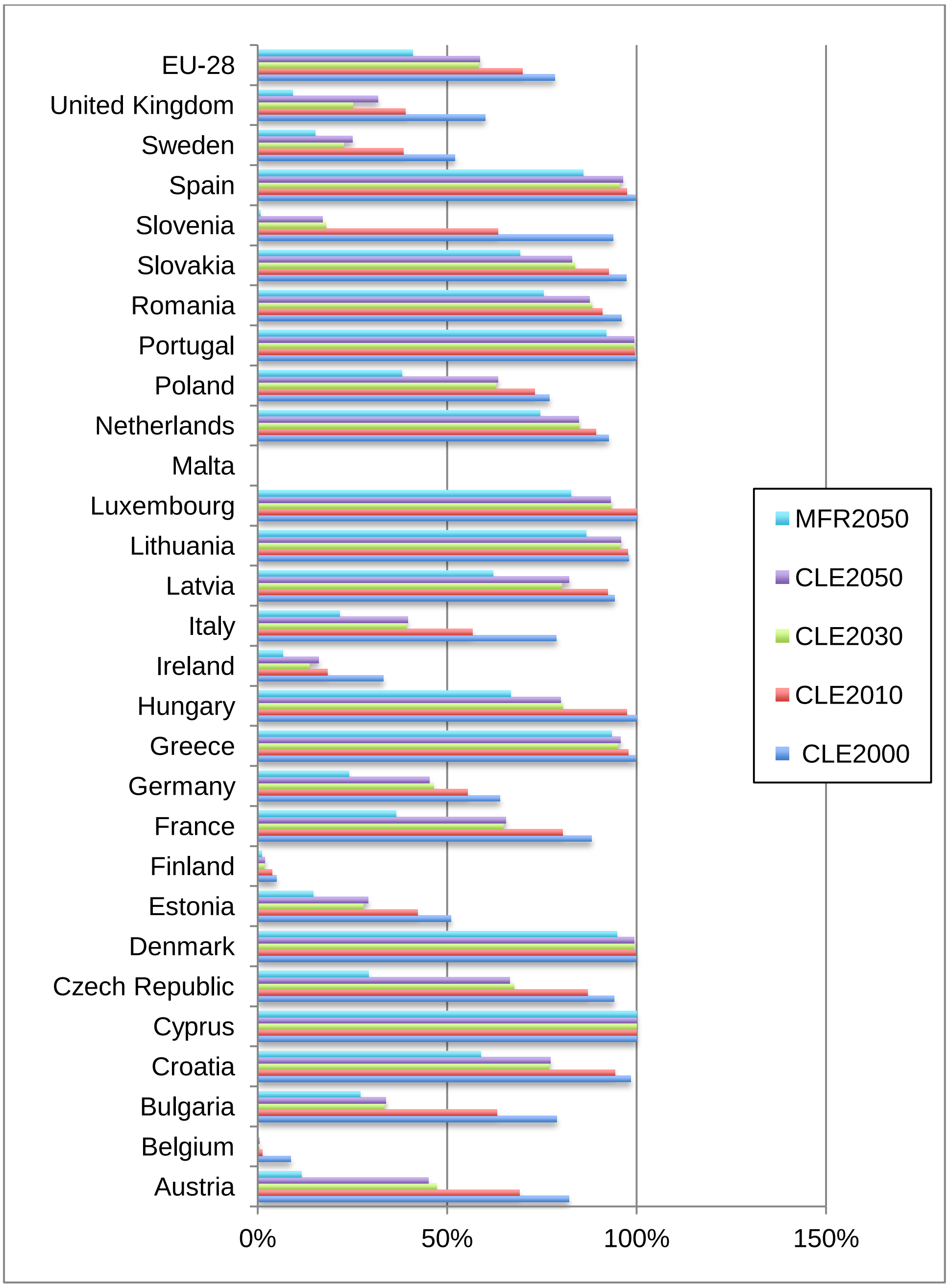

Figure 8. % area of protected ecosystems subject to exceedance of the critical load for N in different scenarios. Source of data: IIASA.

4.2.1 Willingness to pay based estimates

Willingness to pay estimates for protecting these ecosystems are shown in Table 14. The main body of the table is based on the use of a figure of €80/ha, with total damage and benefits from increased abatement scenarios for 2030 and 2050 shown at the foot of the table also for damage based on an estimate of €240/ha.

Table 14. Willingness to pay for ecosystem protection using low (€80/ha) and high (€240/ha) estimates for protected European ecosystems. For rows in italics, protected ecosystem areas have been taken from secondary sources.

Country	**Eco area**	**CLE**	**CLE**	**CLE**	**BIO75**	**MFR**	**CLE**	**BIO75**	**MFR**
		2000	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Austria	*12,324*	*81*	*68*	*47*	*24*	*14*	*44*	*19*	*11*
Belgium	*3,870*	*2.7*	*0.4*	*0.2*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*
Bulgaria	*37,634*	*238*	*190*	*101*	*91*	*82*	*102*	*92*	*82*
Croatia	33	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cyprus	788	6	6	6	6	6	6	6	6
Czech Rep	1,025	8	7	6	4	3	5	3	2
Denmark	1,613	13	13	13	13	12	13	13	12
Estonia	6,159	25	21	14	12	7	14	12	7
Finland	40,051	16	12	6	5	4	6	5	4
France	133,784	944	861	694	545	415	701	508	391
Germany	91,810	469	407	341	242	192	333	204	177
Greece	17,251	138	135	131	130	127	132	130	129
Hungary	12,982	104	101	84	71	70	83	71	69
Ireland	281	1	0	0	0	0	0	0	0
Italy	80,331	507	364	252	177	145	254	168	139
Latvia	5,427	41	40	35	31	27	36	32	27
Lithuania	5,627	44	44	43	42	39	43	42	39
Luxembourg	342	3	3	3	3	2	3	2	2
Malta									
Netherlands	4,599	34	33	31	29	28	31	28	27
Poland	*60,782*	*374*	*356*	*306*	*251*	*191*	*309*	*248*	*185*
Portugal	9,307	74	74	74	70	66	74	72	68
Romania	23,048	177	168	163	155	143	162	152	139
Slovakia	11,117	87	82	74	69	63	74	68	62
Slovenia	7,290	55	37	11	2	1	10	2	0
Spain	91,844	733	716	702	679	621	708	687	631
Sweden	4,844	20	15	9	7	5	10	8	6
UK	*17,683*	*85*	*55*	*36*	*15*	*9*	*45*	*19*	*13*
Total (low)	**549,553**	**4,279**	**3,810**	**3,180**	**2,674**	**2,271**	**3,199**	**2,590**	**2,231**
Benefits vs CLE					**506**	**909**		**609**	**968**
Total (high)					**8,021**	**6,812**	**9,596**	**7,770**	**6,692**
Benefits vs CLE					**1,518**	**2,727**		**1,826**	**2,905**

4.2.2 Restoration cost based estimates

Table 15 shows estimates of economic impact based on the Restoration Cost approach of Ott et al. Overall, estimates are higher than for the WTP approach, though benefits between scenarios are broadly similar. Broken down by pollutant, NH_3 dominates the benefits, though partly because of a substantial decline in NOx leading up to 2030.

Table 15. Benefits based on restoration cost estimates (€million/year).

NOx+NH_3	**CLE**	**CLE**	**CLE**	**BIO75**	**MFR**	**CLE**	**BIO75**	**MFR**
	2000	**2010**	**2030**	**2030**	**2030**	**2050**	**2050**	**2050**
Austria	556	512	369	294	256	360	283	247
Belgium	534	415	316	281	243	305	256	227
Bulgaria	35	32	27	24	23	26	23	22
Croatia	90	86	77	57	41	79	58	42
Cyprus	1	1	1	0	0	1	0	0
Czech Rep.	290	218	155	129	114	148	123	106
Denmark	190	121	83	76	62	78	70	58
Estonia	43	42	36	32	23	35	30	22
Finland	358	312	180	177	142	160	157	117
France	2,125	1,749	1,411	1,182	1,003	1,406	1,101	950
Germany	5,102	4,166	3,169	2,159	1,749	2,968	1,727	1,534
Greece	14	11	7	6	5	7	6	5
Hungary	139	114	83	61	51	82	58	50
Ireland	52	41	34	31	27	35	30	27
Italy	1,719	1,282	1,072	883	821	1,059	846	790
Latvia	24	25	23	21	19	24	21	19
Lithuania	37	42	40	37	25	39	36	24
Luxembourg	86	88	38	34	32	35	31	29
Malta	11	10	5	4	4	5	4	3
Netherlands	961	740	514	499	459	488	473	436
Poland	890	925	683	582	474	667	565	443
Portugal	43	34	31	24	20	33	26	22
Romania	106	84	77	66	58	74	61	54
Slovakia	136	99	82	67	54	76	61	49
Slovenia	140	122	79	65	59	75	61	54
Spain	195	145	125	104	84	131	105	85
Sweden	326	219	121	118	97	124	121	96
United Kingdom	892	550	248	234	184	226	210	158
Total	**15,095**	**12,183**	**9,083**	**7,247**	**6,128**	**8,743**	**6,544**	**5,669**
Benefit vs CLE				**1,836**	**2,955**		**2,200**	**3,074**
Total NOx	**7,747**	**5,570**	**2,554**	**2,390**	**1,948**	**2,222**	**2,024**	**1,587**
NOx benefit vs CLE				**164**	**606**		**198**	**634**
Total NH_3	**7,348**	**6,613**	**6,529**	**4,857**	**4,180**	**6,522**	**4,520**	**4,082**
NH_3 benefit vs CLE				**1,672**	**2,348**		**2,002**	**2,440**

4.2.3 Regulatory revealed preference estimates

Referring back to Figure 8, no country is free from critical loads exceedance under the scenarios investigated in this study. On this basis, using the regulatory revealed preference approach, the full costs of the MFR (Maximum Feasible Reduction) scenario would be added in. In a small number of cases where exceedance appears limited (Belgium, Finland, Ireland) it is possible that some local, more closely targeted and cheaper alternatives are possible. Elsewhere, however, exceedance is so extensive that more drastic measures appear necessary.

Results are shown in Table 16 for 2030 and Table 17 for 2050. Results are larger than for the other two methods, by a factor of about 5 (€10,809 for 2030 and €11,207 for 2050). Results would be still larger if the costs of additional controls on agriculture, for example targeting farms in areas where exceedance was present.

Table 16. Costs of moving from the Current Legislation scenario to the Maximum Technically Feasible Reduction (MTFR) scenario in 2030. Data source: IIASA, units €million/year.

	NOx			NH_3			$NOx+NH_3$
	CLE 2030	**MFR 2030**	**Damage 2030**	**CLE 2030**	**MFR 2030**	**Damage 2030**	**Damage 2030**
Austria	1,404	1,582	179	15	112	97	276
Belgium	1,459	1,614	155	79	194	114	269
Bulgaria	750	829	79	8	47	38	117
Croatia	241	346	105	-	35	35	139
Cyprus	99	108	10	5	18	13	22
Czech Rep.	1,094	1,247	153	29	64	36	189
Denmark	621	712	91	177	263	86	177
Estonia	131	151	20	3	25	22	42
Finland	773	916	143	16	80	64	207
France	7,270	8,146	876	99	774	675	1,551
Germany	8,306	8,946	640	158	1,161	1,003	1,643
Greece	1,349	1,471	122	5	38	33	154
Hungary	771	879	107	22	67	45	153
Ireland	865	937	72	31	118	87	159
Italy	7,553	8,037	484	133	448	315	799
Latvia	246	275	29	3	22	19	48
Lithuania	324	367	43	7	106	99	142
Luxembourg	114	121	6	-	4	4	11
Malta	100	102	2	-	1	1	4
Netherlands	1,782	1,944	162	388	374	-14	148
Poland	6,735	7,443	707	95	634	540	1,247
Portugal	1,132	1,240	108	14	94	80	188
Romania	1,453	1,657	204	24	113	89	293
Slovakia	604	675	70	6	28	22	92
Slovenia	299	324	25	5	17	11	37
Spain	5,930	6,557	626	311	993	681	1,308
Sweden	882	974	91	15	73	59	150
United Kingdom	6,849	7,953	1,104	67	207	140	1,245
EU-28	**59,135**	**65,550**	**6,415**	**1,714**	**6,108**	**4,394**	**10,809**

Table 17. Costs of moving from the Current Legislation scenario to the Maximum Technically Feasible Reduction (MTFR) scenario in 2050. Data source: IIASA, units €million/year.

	NOx			NH_3			$NOx+NH_3$
	CLE 2050	**MFR 2050**	**Damage 2050**	**CLE 2050**	**MFR 2050**	**Damage 2050**	**Damage 2050**
Austria	1,587	1,831	245	15	112	97	342
Belgium	1,798	1,990	192	75	194	119	311
Bulgaria	740	822	82	9	47	37	119
Croatia	280	372	92	-	35	35	127
Cyprus	123	131	8	6	18	12	21
Czech Rep.	1,262	1,437	175	29	64	35	209
Denmark	709	806	97	186	263	76	173
Estonia	139	158	19	4	25	20	40
Finland	841	995	154	17	80	63	217
France	8,230	9,140	910	102	774	672	1,582
Germany	7,910	8,655	745	160	1,161	1,001	1,746
Greece	1,522	1,654	132	6	38	32	163
Hungary	971	1,072	101	23	67	44	145
Ireland	1,089	1,162	74	33	118	85	159
Italy	7,863	8,362	499	149	448	300	799
Latvia	277	310	33	4	22	18	51
Lithuania	421	460	39	9	106	97	136
Luxembourg	128	134	6	-	4	4	10
Malta	107	109	2	-	1	1	3
Netherlands	1,796	1,960	164	364	374	10	173
Poland	6,728	7,462	735	120	634	514	1,249
Portugal	1,299	1,412	113	15	94	79	192
Romania	1,662	1,880	218	22	113	90	308
Slovakia	666	733	67	6	28	22	89
Slovenia	319	354	35	5	17	11	46
Spain	6,938	7,586	647	385	993	608	1,255
Sweden	921	1,047	127	16	73	57	184
United Kingdom	8,218	9,441	1,223	71	207	136	1,359
EU-28	**64,545**	**71,475**	**6,930**	**1,832**	**6,108**	**4,276**	**11,207**

4.3 Discussion

The estimated benefits from use of the three approaches described above are summarised in Table 18. There is roughly a factor 10 from the highest to the lowest estimates. There is some correspondence between the high estimates base on the WTP method and the repair cost method, though this similarity could be considered coincidental. More usefully, the results indicate that even when using radically different methods, estimates of benefits are within an order of magnitude of each other.

Table 18. Summary of values of ecosystem benefits for moving between pairs of scenarios for 2030 and 2050. Units: €million/year.

	2030		2050	
	CLE-BIO75	**CLE-MFR**	**CLE-BIO75**	**CLE-MFR**
WTP (low)	506	909	609	968
WTP (high)	1,518	2,727	1,826	2,905
Repair cost	1,836	2,955	2,200	3,074
Regulatory revealed preference	n/a	10,089	n/a	11,207

As stated earlier, the preferred approach identified here is the use of estimates of willingness to pay to protect ecosystems. Of the three approaches, this is the one with the most explicit link to the good being valued: ecosystem protection. The repair cost approach has several problems, including:

- The concept of restoration is questionable. After restoration an ecosystem may look the same as it was originally. However, even where species are reintroduced successfully there will be a loss of genetic stock. This can bring its own problems: a restricted genetic stock has been identified as a major risk factor for the spread of certain diseases including Ash Dieback. The fine detail (for example the range of soil invertebrates present) will also be different. Hence there is a real question of the extent to which restoration goes beyond cosmetic improvement.
- The definition of 'restored' requires some reference position to be adopted. This may require some rather arbitrary decisions to be taken (as implied by Ott et al's referencing to the Swiss lowlands). One possible reference point might be thought of as the date at which legislation such as the Birds and Habitats Directives were passed. However, the driver for this legislation was environmental degradation, so conditions when the Directives were passed will not represent the undamaged state.
- There is a question of whether society will think that restoration is worthwhile. If a site is not restored the WTP for its protection can be concluded to be lower than the restoration cost. This problem is partially overcome by limiting analysis to Natura 2000 sites because of the legal mandate that they should not be allowed to deteriorate, which is not met whilst critical loads and levels are exceeded.

It is notable that Ott et al themselves identified a series of issues with their method:

- The approach assumes that the cost of replacing an ecosystem or its services is an estimate of the value of the ecosystem or its services. To the extent that restoration is applied, the cost of restoration can only be regarded as a minimum estimate. To the extent that restoration is not applied, a conclusion may be that the costs exceed the benefits of action, that benefits have been underestimated (qualitatively or quantitatively), or simply that funding for restoration is unavailable.
- The approach is not based on individual preferences but on an ecological or expert standard and the cost to re-establish this standard.
- Proposed interventions may not be a perfect substitute for the lost ecosystem service, e.g. existence values of certain species or ecosystems are not replaceable.
- Some damage may not be recognised immediately, or, like the effects of gradual eutrophication of ecosystems, may take many years to reach steady state.
- Restoration may bring a variety of benefits that are not recognised through the restoration costs (Pearce and Moran, 1994).

To the extent that restoration is undertaken it can reasonably be said that associated costs provide some insight, but only as a minimum estimate (minimum on the basis that WTP has to be at least as large as the restoration cost for action to be carried out, but could be larger). The need to restore indicates that some level of damage has occurred that society finds unacceptable, and this has a cost: one would not restore for the simple sake of restoration.

The revealed preference approach is also problematic:

- The Birds Directive was first adopted in 1979, and the Habitats Directive in 1992. It is not clear to what extent the policy makers involved in this process were aware of the threats posed by nitrogenous air pollutants.
- It is unclear to what extent subsequent revisions of the Directives have paid attention to damage caused by air pollution, though the 7th Environmental Action Programme of the European Commission reconfirms the need of meeting critical loads (no significant damage to ecosystems) by 2050. However, to the extent that some policy makers may have been aware of the threat of air pollution, they may have regarded it as being dealt with directly through air pollution legislation and hence not of their concern.
- Existing air quality polices are developed against health, as well as ecological objectives.

Set against this, policy makers are able to review and revise targets as they consider necessary. So far, this has not been done for the Birds and Habitats Directives, although those responsible for implementation of those Directives are by now certainly familiar with the problems associated with air pollution.

Again, issues are partially offset by considering the approach not in isolation, but as providing an alternative perspective to the methods discussed above. The approach is also useful for stressing the difficulty in ensuring the health of sites designated for protection given the burdens imposed by transboundary air pollution.

The willingness to pay approach is also not without its problems. There is a clear need for further original valuation work that permits appreciation of marginal changes in biodiversity of the kind considered here to be quantified, in a number of countries in addition to the UK. This should also take into account impacts to different types of ecosystem (work of this nature is underway in the UK). Linkage to species richness, or some other meaningful index of biodiversity would also be beneficial, in contrast to the current link to exceedance of critical loads. There are then further issues associated with the ability of individual respondents to understand the complexity of the range of ecosystem services at risk, and questions as to whether the long term interests of society including future generations are well served by adopting the values of the current generation.

From the perspective of environmental economics, preference would go to the WTP based method, but the choice becomes less clear when considering the strengths and weaknesses of each approach.

5 Health impact assessment

Health impact assessment has not been further developed through the ECLAIRE study, though is included here for the purposes of comparison with the impacts to ecosystem services.

5.1 Methods

The analysis of health impacts presented here follows the recommendations of the REVIHAAP (Review of Health Aspects of Air Pollution) and HRAPIE (Health Response to Air Pollutants in Europe) studies of WHO, undertaken to inform the revision of the European Commission’s Thematic Strategy on Air Pollution (WHO, 2013a, b). A more complete description of the methods as applied here is available from Holland (2014a, b). In practice it has not been possible to apply the HRAPIE recommendations in full. The main reasons for this are:

- For ozone, exposure data for the SOMO10 metric are not currently unavailable.
- For NO_2, there is a lack of agreement regarding the extent to which exposure data quantified using EMEP outputs properly reflect exposure of the population. Quantification of NO_2 effects has therefore not been attempted.
- For effects of chronic exposure to ozone and NO_2 (leaving aside the issues of exposure modelling) on mortality, protocols for dealing with the potential for double counting against the function applied for $PM_{2.5}$ have not been agreed. Neither is therefore added into total benefits. The HRAPIE report states that: ”*Some of the long-term NO_2 effects may overlap with effects from long-term $PM_{2.5}$ (up to 33%)*.” This statement could of course be turned around to say that at least 67% of the NO_2 impact is not accounted for within the $PM_{2.5}$ function, providing a bias to underestimation.

Table 19. List of health impacts – HRAPIE recommendations. Functions in italics have not been applied here.

Impact / population group	Rating	Population	Exposure metric
All cause mortality from chronic exposure	*B*	*Over 30 years*	*O_3, SOMO35, summer months*
All cause mortality from acute exposure	A*/A	All ages	O_3, SOMO35 (A*), SOMO10 (A)
Cardiac and respiratory mortality from acute exposure	*A*	*All ages*	*O_3, SOMO35 (A*), SOMO10 (A)*
Respiratory Hospital Admissions	A*/A	Over 65 years	O_3, SOMO35 (A*), SOMO10 (A)
Cardiovascular hospital admissions	A*/A	Over 65 years	O_3, SOMO35 (A*), SOMO10 (A)
Minor Restricted Activity Days (MRADs)	B*/B	All ages	O_3, SOMO35 (B*), SOMO10 (B)
All cause mortality from chronic exposure as life years lost or premature deaths	A*	Over 30 years	$PM_{2.5}$, annual average
Cause-specific mortality from chronic exposure	*A*	*Over 30 years*	*$PM_{2.5}$, annual average*
Infant Mortality	B*	1 month to 1 year	$PM_{2.5}$, annual average
Chronic bronchitis in adults	B*	Over 27 years	$PM_{2.5}$, annual average
Bronchitis in children	B*	6 – 12 years	$PM_{2.5}$, annual average
All cause mortality from acute exposure	A	All ages	$PM_{2.5}$, annual average
Respiratory Hospital Admissions	A*	All ages	$PM_{2.5}$, annual average
Cardiovascular Hospital Admissions	A*	All ages	$PM_{2.5}$, annual average
Restricted Activity Days (RADs)	B*	All	$PM_{2.5}$, annual average
Including lost working days	B*	15 to 64 years	$PM_{2.5}$, annual average
Asthma symptoms in asthmatic children	B*	5 to 19 years	$PM_{2.5}$, annual average
All cause mortality from chronic exposure	*B**	*Over 30 years*	*NO_2 annual mean >20ug.m^{-3}*
All cause mortality from acute exposure	*A**	*All ages*	*NO_2 annual mean*
Bronchitis in children	*B**	*5 – 14 years*	*NO_2 annual mean*
Respiratory hospital admissions	*A**	*All ages*	*NO_2 annual mean*

Valuation is performed by multiplying impacts (e.g. respiratory hospital admissions) by an appropriate estimate of the unit value of each impact (e.g. the cost of a respiratory hospital admission). Unit values seek to describe the full economic effect of the impacts that they are linked with. This includes elements associated with the costs of health care, lost productivity amongst workers and aversion to premature death or ill health. The values used here are shown in Table 20.

Table 20. Values for the health impact assessment (price year 2005)

Impact / population group	Unit cost	Unit
Ozone effects		
Mortality from chronic exposure as: Life years lost, or Premature deaths	57,700 / 133,000 1.09 / 2.22 million	€/life year lost (VOLY) €/death (VSL)
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Respiratory Hospital Admissions	2,220	€/hospital admission
Cardiovascular Hospital Admissions	2,220	€/hospital admission
Minor Restricted Activity Days (MRADs)	42	€/day
$PM_{2.5}$ effects		
Mortality from chronic exposure as: Life years lost, or Premature deaths (all-cause and cause-specific mortality)	57,700 / 133,000 1.09 / 2.22 million	€/life year lost (VOLY) €/death (VSL)
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Infant Mortality	1.6 to 3.3 million	€/case
Chronic Bronchitis in adults	53,600	€/new case of chronic bronchitis
Bronchitis in children	588	€/case
Respiratory Hospital Admissions	2,220	€/hospital admission
Cardiac Hospital Admissions	2,220	€/hospital admission
Restricted Activity Days (RADs)	92	€/day
Work loss days	130	€/day
Asthma symptoms, asthmatic children	42	€/day
NO_2 effects (though not quantified in this report)		
Mortality from chronic exposure as: Life years lost, or Premature deaths	57,700 / 133,000 1.09 / 2.22 million	€/life year lost (VOLY) €/death (VSL)
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Bronchitis in children	588	€/case
Respiratory Hospital Admissions	2,220	€/hospital admission

5.2 Results

Results are presented below, showing total health impacts in the EU28 for each scenario (Table 21), benefits in terms of the reduction of impacts of each type (Table 22), the monetised equivalent of each impact (Table 23) and the economic benefit of emission reductions compared to the Current Legislation (CLE) scenarios (Table 24).

Table 21. Health impacts under each scenario for the EU28

IMPACTS (thousands)			**CLE**	**CLE**	**CLE**	**CLE**
			2000	**2010**	**2030**	**2050**
Acute Mortality	Deaths	O3	33	27	24	27
Respiratory hospital admissions	Cases	O3	21	19	21	26
Cardiovascular hospital admissions	Cases	O3	94	87	90	110
Minor Restricted Activity Days	Days	O3	140,000	110,000	86,000	86,000
Chronic Mortality (30yr+)	Life years lost	PM	6,000	4,100	2,600	2,300
Chronic Mortality (30yr+)	Deaths	PM	510	380	310	340
Infant Mortality (1 month to 1yr)	Deaths	PM	1	1	0	0
Chronic Bronchitis (27yr +)	Cases	PM	400	320	240	230
Bronchitis in children aged 6 to 12	Cases	PM	1,600	1,100	750	710
Respiratory Hospital Admissions	Cases	PM	190	140	100	99
Cardiac Hospital Admissions	Cases	PM	180	140	97	92
Restricted Activity Days	Days	PM	580,000	440,000	330,000	320,000
Asthma symptom days (children 5-19yr)	Days	PM	17,000	11,000	7,900	7,600
Lost working days (15-64 years)	Days	PM	160,000	120,000	78,000	66,000
IMPACTS (thousands)			**CLE**	**BIO75**	**MFR**	
			2030	**2030**	**2030**	
Acute Mortality	Deaths	O3	24	23	20	
Respiratory hospital admissions	Cases	O3	21	20	18	
Cardiovascular hospital admissions	Cases	O3	90	87	78	
Minor Restricted Activity Days	Days	O3	86,000	82,000	74,000	
Chronic Mortality (30yr+)	Life years lost	PM	2,600	2,200	2,000	
Chronic Mortality (30yr+)	Deaths	PM	310	260	240	
Infant Mortality (1 month to 1yr)	Deaths	PM	0	0	0	
Chronic Bronchitis (27yr +)	Cases	PM	240	200	180	
Bronchitis in children aged 6 to 12	Cases	PM	750	630	570	
Respiratory Hospital Admissions	Cases	PM	100	86	78	
Cardiac Hospital Admissions	Cases	PM	97	82	74	
Restricted Activity Days	Days	PM	330,000	270,000	250,000	
Asthma symptom days (children 5-19yr)	Days	PM	7,900	6,600	6,000	
Lost working days (15-64 years)	Days	PM	78,000	65,000	59,000	
IMPACTS (thousands)			**CLE**	**BIO75**	**MFR**	
			2050	**2050**	**2050**	
Acute Mortality	Deaths	O3	27	26	24	
Respiratory hospital admissions	Cases	O3	26	25	22	
Cardiovascular hospital admissions	Cases	O3	110	110	95	
Minor Restricted Activity Days	Days	O3	86,000	83,000	74,000	
Chronic Mortality (30yr+)	Life years lost	PM	2,300	1,900	1,700	
Chronic Mortality (30yr+)	Deaths	PM	340	290	260	
Infant Mortality (1 month to 1yr)	Deaths	PM	0	0	0	
Chronic Bronchitis (27yr +)	Cases	PM	230	190	180	
Bronchitis in children aged 6 to 12	Cases	PM	710	600	540	
Respiratory Hospital Admissions	Cases	PM	99	83	75	
Cardiac Hospital Admissions	Cases	PM	92	77	70	
Restricted Activity Days	Days	PM	320,000	270,000	250,000	
Asthma symptom days (children 5-19yr)	Days	PM	7,600	6,400	5,800	
Lost working days (15-64 years)	Days	PM	66,000	55,000	50,000	

Table 22. Benefits (reduction in health impacts) for the EU28. Upper block: benefits relative to CLE2000. Middle block: benefits relative to CLE2030. Bottom block: benefits relative to CLE2050.

BENEFITS (thousands)			**CLE**	**CLE**	**CLE**
			2010	**2030**	**2050**
Acute Mortality	Deaths	O3	7	10	11
Respiratory hospital admissions	Cases	O3	2	0	1
Cardiovascular hospital admissions	Cases	O3	7	4	8
Minor Restricted Activity Days	Days	O3	27,000	51,000	54,000
Chronic Mortality (30yr+)	Life years lost	PM	1,900	3,400	3,800
Chronic Mortality (30yr+)	Deaths	PM	130	200	250
Infant Mortality (1 month to 1yr)	Deaths	PM	1	1	1
Chronic Bronchitis (27yr +)	Cases	PM	84	160	200
Bronchitis in children aged 6 to 12	Cases	PM	530	860	980
Respiratory Hospital Admissions	Cases	PM	48	88	100
Cardiac Hospital Admissions	Cases	PM	43	82	98
Restricted Activity Days	Days	PM	140,000	250,000	310,000
Asthma symptom days (children 5-19yr)	Days	PM	5,600	9,000	10,000
Lost working days (15-64 years)	Days	PM	41,000	85,000	98,000
BENEFITS (thousands)			**BIO75**	**MFR**	
			2030	**2030**	
Acute Mortality	Deaths	O3	1	3	
Respiratory hospital admissions	Cases	O3	1	3	
Cardiovascular hospital admissions	Cases	O3	3	12	
Minor Restricted Activity Days	Days	O3	3,200	11,000	
Chronic Mortality (30yr+)	Life years lost	PM	420	620	
Chronic Mortality (30yr+)	Deaths	PM	50	75	
Infant Mortality (1 month to 1yr)	Deaths	PM	0	0	
Chronic Bronchitis (27yr +)	Cases	PM	39	57	
Bronchitis in children aged 6 to 12	Cases	PM	120	180	
Respiratory Hospital Admissions	Cases	PM	17	25	
Cardiac Hospital Admissions	Cases	PM	16	23	
Restricted Activity Days	Days	PM	53,000	79,000	
Asthma symptom days (children 5-19yr)	Days	PM	1,300	1,900	
Lost working days (15-64 years)	Days	PM	13,000	19,000	
BENEFITS (thousands)			**BIO75**	**MFR**	
			2050	**2050**	
Acute Mortality	Deaths	O3	1	4	
Respiratory hospital admissions	Cases	O3	1	3	
Cardiovascular hospital admissions	Cases	O3	4	15	
Minor Restricted Activity Days	Days	O3	3,200	12,000	
Chronic Mortality (30yr+)	Life years lost	PM	370	550	
Chronic Mortality (30yr+)	Deaths	PM	57	84	
Infant Mortality (1 month to 1yr)	Deaths	PM	0	0	
Chronic Bronchitis (27yr +)	Cases	PM	38	56	
Bronchitis in children aged 6 to 12	Cases	PM	120	170	
Respiratory Hospital Admissions	Cases	PM	16	24	
Cardiac Hospital Admissions	Cases	PM	15	23	
Restricted Activity Days	Days	PM	53,000	79,000	
Asthma symptom days (children 5-19yr)	Days	PM	1,200	1,800	
Lost working days (15-64 years)	Days	PM	11,000	16,000	

Presentation of the monetised results is complicated by the existence of different views on the appropriate approach to valuation of mortality (whether in terms of reduced life expectancy or ‘deaths’, and different views of various bodies on the appropriate value to use for these metrics). For this reason there are 6 alternative estimates of total damage given in the aggregated estimates at the foot of each table. The estimate corresponding to the one given most prominence in studies for the European Commission is the ‘mid VOLY’ case, highlighted in the tables that follow.

Table 23. Monetised equivalent for health impacts under each scenario for the EU28

Damage, billion Euro/year				**CLE**	**CLE**	**CLE**	**CLE**
				2000	**2010**	**2030**	**2050**
Acute Mortality	A*	Low VOLY	O3	1.3	1.1	0.9	1.1
Acute Mortality	A*	Median VOLY	O3	1.9	1.5	1.4	1.6
Acute Mortality	A*	High VOLY	O3	4.6	3.7	3.3	3.8
Respiratory hospital admissions	A*		O3	0.05	0.04	0.05	0.06
Cardiovascular hospital admissions	A*		O3	0.21	0.19	0.20	0.25
Minor Restricted Activity Days	B*		O3	5.7	4.6	3.6	3.6
Chronic Mortality (30yr+)	A*	Low VOLY	PM	240	160	100	91
Chronic Mortality (30yr+)	A*	Median VOLY	PM	350	230	150	130
Chronic Mortality (30yr+)	A*	High VOLY	PM	830	560	360	320
Chronic Mortality (30yr+)	A*	Low VSL	PM	560	420	340	380
Chronic Mortality (30yr+)	A*	Median VSL	PM	1,100	850	690	770
Chronic Mortality (30yr+)	A*	High VSL	PM	1,400	1,100	870	960
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	2.3	1.3	0.66	0.55
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	4.8	2.6	1.3	1.1
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	6.0	3.3	1.7	1.4
Chronic Bronchitis (27yr +)	B*		PM	22	17	13	12
Bronchitis in children aged 6 to 12	B*		PM	0.95	0.63	0.44	0.42
Respiratory Hospital Admissions	A*		PM	0.42	0.32	0.23	0.22
Cardiac Hospital Admissions	A*		PM	0.40	0.30	0.22	0.20
Restricted Activity Days	B*		PM	54	40	30	30
Asthma symptom days (children 5-19yr)	B*		PM	0.71	0.48	0.33	0.32
Lost working days (15-64 years)	B*		PM	21	16	10	8.5
Aggregated damage							
Low VOLY				**350**	**240**	**160**	**150**
Mid VOLY				**460**	**320**	**210**	**190**
High VOLY				**950**	**650**	**420**	**380**
Low VSL				**670**	**500**	**400**	**430**
Mid VSL				**1,200**	**930**	**750**	**820**
High VSL				**1,500**	**1,200**	**930**	**1,000**

Damage, billion Euro/year				**CLE**	**BIO75**	**MFR**
				2030	**2030**	**2030**
Acute Mortality	A*	Low VOLY	O3	0.9	0.9	0.8
Acute Mortality	A*	Median VOLY	O3	1.4	1.3	1.2
Acute Mortality	A*	High VOLY	O3	3.3	3.1	2.8
Respiratory hospital admissions	A*		O3	0.05	0.04	0.04
Cardiovascular hospital admissions	A*		O3	0.20	0.19	0.17
Minor Restricted Activity Days	B*		O3	3.6	3.5	3.1
Chronic Mortality (30yr+)	A*	Low VOLY	PM	100	87	79
Chronic Mortality (30yr+)	A*	Median VOLY	PM	150	130	110
Chronic Mortality (30yr+)	A*	High VOLY	PM	360	300	270
Chronic Mortality (30yr+)	A*	Low VSL	PM	340	280	260
Chronic Mortality (30yr+)	A*	Median VSL	PM	690	580	520
Chronic Mortality (30yr+)	A*	High VSL	PM	870	730	660
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	0.66	0.55	0.50
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	1.3	1.1	1.0
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	1.7	1.4	1.3
Chronic Bronchitis (27yr +)	B*		PM	13	11	9.7
Bronchitis in children aged 6 to 12	B*		PM	0.44	0.37	0.33
Respiratory Hospital Admissions	A*		PM	0.23	0.19	0.17
Cardiac Hospital Admissions	A*		PM	0.22	0.18	0.16
Restricted Activity Days	B*		PM	30	25	23
Asthma symptom days (5-19yr)	B*		PM	0.33	0.28	0.25
Lost working days (15-64 years)	B*		PM	10	8.5	7.7
Aggregated damage						
Low VOLY				**160**	**140**	**120**
Mid VOLY				**210**	**180**	**160**
High VOLY				**420**	**350**	**320**
Low VSL				**400**	**330**	**300**
Mid VSL				**750**	**630**	**570**
High VSL				**930**	**780**	**710**

Table 23 (continued). Monetised equivalent for health impacts under each scenario for the EU28

Damage, billion Euro/year				**CLE**	**BIO75**	**MFR**
				2050	**2050**	**2050**
Acute Mortality	A*	Low VOLY	O3	1.1	1.1	0.9
Acute Mortality	A*	Median VOLY	O3	1.6	1.5	1.4
Acute Mortality	A*	High VOLY	O3	3.8	3.6	3.3
Respiratory hospital admissions	A*		O3	0.06	0.06	0.05
Cardiovascular hospital admissions	A*		O3	0.25	0.24	0.21
Minor Restricted Activity Days	B*		O3	3.6	3.5	3.1
Chronic Mortality (30yr+)	A*	Low VOLY	PM	91	76	69
Chronic Mortality (30yr+)	A*	Median VOLY	PM	130	110	99
Chronic Mortality (30yr+)	A*	High VOLY	PM	320	260	240
Chronic Mortality (30yr+)	A*	Low VSL	PM	380	310	280
Chronic Mortality (30yr+)	A*	Median VSL	PM	770	640	580
Chronic Mortality (30yr+)	A*	High VSL	PM	960	810	730
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	0.55	0.46	0.42
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	1.1	0.94	0.85
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	1.4	1.2	1.1
Chronic Bronchitis (27yr +)	B*		PM	12	10	9.4
Bronchitis in children aged 6 to 12	B*		PM	0.42	0.35	0.32
Respiratory Hospital Admissions	A*		PM	0.22	0.18	0.17
Cardiac Hospital Admissions	A*		PM	0.20	0.17	0.15
Restricted Activity Days	B*		PM	30	25	23
Asthma symptom days (5-19yr)	B*		PM	0.32	0.27	0.24
Lost working days (15-64 years)	B*		PM	8.5	7.1	6.5
Aggregated damage						
Low VOLY				**150**	**120**	**110**
Mid VOLY				**190**	**160**	**140**
High VOLY				**380**	**320**	**290**
Low VSL				**430**	**360**	**330**
Mid VSL				**820**	**690**	**620**
High VSL				**1,000**	**860**	**780**

Table 24. Economic benefits (reduction in health damage) for the EU28. Upper block: benefits relative to CLE2000. Middle block: benefits relative to CLE2030. Bottom block: benefits relative to CLE2050.

BENEFITS, billion Euro/year				CLE	CLE	CLE
				2010	**2030**	**2050**
Acute Mortality	A*	Low VOLY	O3	0.3	0.4	0.3
Acute Mortality	A*	Median VOLY	O3	0.4	0.6	0.4
Acute Mortality	A*	High VOLY	O3	0.9	1.4	0.9
Respiratory hospital admissions	A*		O3	0.0	0.0	0.0
Cardiovascular hospital admissions	A*		O3	0.0	0.0	0.0
Minor Restricted Activity Days	B*		O3	1.1	2.1	2.1
Chronic Mortality (30yr+)	A*	Low VOLY	PM	78	140	150
Chronic Mortality (30yr+)	A*	Median VOLY	PM	110	200	210
Chronic Mortality (30yr+)	A*	High VOLY	PM	270	470	520
Chronic Mortality (30yr+)	A*	Low VSL	PM	140	220	180
Chronic Mortality (30yr+)	A*	Median VSL	PM	290	450	370
Chronic Mortality (30yr+)	A*	High VSL	PM	370	560	470
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	1.1	1.7	1.8
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	2.2	3.4	3.7
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	2.7	4.3	4.6
Chronic Bronchitis (27yr +)	B*		PM	4.5	8.8	9.1
Bronchitis in children aged 6 to 12	B*		PM	0.3	0.5	0.5
Respiratory Hospital Admissions	A*		PM	0.1	0.2	0.2
Cardiac Hospital Admissions	A*		PM	0.1	0.2	0.2
Restricted Activity Days	B*		PM	13	23	24
Asthma symptom days (children 5-19yr)	B*		PM	0.2	0.4	0.4
Lost working days (15-64 years)	B*		PM	5.3	11	13
Aggregated benefits						
Low VOLY				**100**	**190**	**200**
Mid VOLY				**140**	**250**	**270**
High VOLY				**300**	**530**	**570**
Low VSL				**170**	**270**	**230**
Mid VSL				**320**	**500**	**420**
High VSL				**390**	**620**	**520**

BENEFITS, billion Euro/year				BIO75	MFR
				2030	**2030**
Acute Mortality	A*	Low VOLY	O3	0.04	0.13
Acute Mortality	A*	Median VOLY	O3	0.05	0.18
Acute Mortality	A*	High VOLY	O3	0.12	0.44
Respiratory hospital admissions	A*		O3	0.00	0.01
Cardiovascular hospital admissions	A*		O3	0.01	0.03
Minor Restricted Activity Days	B*		O3	0.13	0.48
Chronic Mortality (30yr+)	A*	Low VOLY	PM	17	25
Chronic Mortality (30yr+)	A*	Median VOLY	PM	24	36
Chronic Mortality (30yr+)	A*	High VOLY	PM	58	86
Chronic Mortality (30yr+)	A*	Low VSL	PM	55	81
Chronic Mortality (30yr+)	A*	Median VSL	PM	110	170
Chronic Mortality (30yr+)	A*	High VSL	PM	140	210
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	0.11	0.16
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	0.22	0.32
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	0.28	0.40
Chronic Bronchitis (27yr +)	B*		PM	2.1	3.1
Bronchitis in children aged 6 to 12	B*		PM	0.07	0.10
Respiratory Hospital Admissions	A*		PM	0.04	0.06
Cardiac Hospital Admissions	A*		PM	0.04	0.05
Restricted Activity Days	B*		PM	4.9	7.2
Asthma symptom days (children 5-19yr)	B*		PM	0.05	0.08
Lost working days (15-64 years)	B*		PM	1.6	2.4
Aggregated benefits					
Low VOLY				**26**	**39**
Mid VOLY				**34**	**50**
High VOLY				**68**	**100**
Low VSL				**64**	**95**
Mid VSL				**120**	**180**
High VSL				**150**	**220**

Table 24 (continued). Monetised equivalent for health impacts under each scenario for the EU28

BENEFITS, billion Euro/year				**BIO75**	**MFR**
				2030	**2030**
Acute Mortality	A*	Low VOLY	O3	0.04	0.15
Acute Mortality	A*	Median VOLY	O3	0.06	0.21
Acute Mortality	A*	High VOLY	O3	0.14	0.52
Respiratory hospital admissions	A*		O3	0.00	0.01
Cardiovascular hospital admissions	A*		O3	0.01	0.03
Minor Restricted Activity Days	B*		O3	0.13	0.49
Chronic Mortality (30yr+)	A*	Low VOLY	PM	15	22
Chronic Mortality (30yr+)	A*	Median VOLY	PM	21	32
Chronic Mortality (30yr+)	A*	High VOLY	PM	52	77
Chronic Mortality (30yr+)	A*	Low VSL	PM	62	91
Chronic Mortality (30yr+)	A*	Median VSL	PM	130	190
Chronic Mortality (30yr+)	A*	High VSL	PM	160	240
Infant Mortality (1 month to 1yr)	B*	Low VSL	PM	0.09	0.13
Infant Mortality (1 month to 1yr)	B*	Median VSL	PM	0.18	0.27
Infant Mortality (1 month to 1yr)	B*	High VSL	PM	0.23	0.34
Chronic Bronchitis (27yr +)	B*		PM	2.0	3.0
Bronchitis in children aged 6 to 12	B*		PM	0.07	0.10
Respiratory Hospital Admissions	A*		PM	0.04	0.06
Cardiac Hospital Admissions	A*		PM	0.04	0.05
Restricted Activity Days	B*		PM	4.8	7.2
Asthma symptom days (children 5-19yr)	B*		PM	0.05	0.08
Lost working days (15-64 years)	B*		PM	1.4	2.1
Aggregated benefits					
Low VOLY				**24**	**36**
Mid VOLY				**30**	**46**
High VOLY				**61**	**91**
Low VSL				**70**	**100**
Mid VSL				**130**	**200**
High VSL				**170**	**250**

5.3 Discussion

The results presented in this section demonstrate that substantial impacts of air pollution on health are predicted out to 2050, although no quantification of effects linked to NO_2 exposure could be attempted. This raises the question of by how much impacts might increase. It is noted that the investigation of the impacts of NO_2 on health is a very active area for epidemiological research, and so the precise approach for quantification of health impacts from NO_2 exposure may in future vary from that recommended by the HRAPIE study (WHO, 2013b). However, if methods are not substantially different, it would be expected that NO_2 related impacts would be substantial with potential for adjustment of air pollution policies more towards NOx reduction. This could then affect the extent to which emissions of NOx are prioritised for reduction in comparison to emissions of, for example, SO_2 or $PM_{2.5}$.

6 Discussion

Table 25 summarises estimates presented in the previous chapters of the economic value of damage to ecosystems from ozone and nitrogen deposition, and to health from exposure to fine particles and ozone.

Table 25. Summary of damage estimates, all figures €billion/year. Shading indicates alternative estimates for the same effect.

	CLE	CLE	CLE	BIO75 i77	MFR
	2000	2010	2030	2030	2030
Crops	9.2	7.9	6.6	6.5	6.2
Crops (climate adj)	n/a	n/a	8.9	n/a	8.4
Forest, climate	1.3 - 15	1.1 - 14	4.0 - 31	4.0 - 30	3.8 - 29
Forest production	2.4 - 3.7	2.1 - 3.3	1.9 - 3.0	1.9 - 2.9	1.8 - 2.8
Biodiversity (WTP)	4.3 - 13	3.8 - 11	3.2 - 9.5	2.7 - 8.0	2.3 - 6.8
Biodiversity (repair cost)	15	12	9	7	6
Biodiversity (Reg. rev. pref)	n/a	n/a	n/a	n/a	n/a
Health	460	320	210	180	160
Health (range)	350 - 1500	240 - 1200	160 - 930	140 - 780	120 - 710

	CLE	BIO75 i78	MFR
	2050	2050	2050
Crops	6.5	6.4	6.2
Crops (climate adj)	11.8	n/a	11.1
Forest, climate	4.0 - 30	3.9 - 30	3.8 - 29
Forest production	1.9 - 2.9	1.9 - 2.9	1.8 - 2.8
Biodiversity (WTP)	3.2 - 9.6	2.6 - 7.8	2.2 - 6.7
Biodiversity (repair cost)	9	7	6
Biodiversity (Reg. rev. pref)	n/a	n/a	n/a
Health	190	160	140
Health (range)	150 - 1000	120 - 860	110 - 780

Note: no estimates are provided for the regulatory revealed preference approach for valuation of ecosystem impacts in this table, as abatement cost data already incurred are not specific to ecosystem improvement, but include existing concerns over health impacts also.

Table 26 provides estimates of the benefits of moving from the current legislation (CLE) scenario to the BIO75 policy scenario and MFR scenario in 2030 and 2050. Shading in the tables indicates alternative estimates for the same effect, and results for any scenario within the same group (i.e. the 2 estimates for crop production and the 3 estimates for biodiversity) should not be added together. The row titled 'Ecosystems range' seeks to provide some overall summary of several rows of data. For consistency with the MFR scenarios it has been necessary to calculate an illustrative figure for the 'regulatory revealed preference approach for the BIO75 scenarios for 2030 and 2050: this is done by adjusting the MFR estimate (€11 billion/year in both cases) by the ratio for the benefits of BIO75:MFR using the repair cost method.

Table 26. Summary of benefit estimates relative to current legislation (CLE) scenario for each year, all figures €billion/year. Shading indicates alternative estimates for the same effect.

	BIO75 i77	**MFR**	**BIO75 i78**	**MFR**
	2030	**2030**	**2050**	**2050**
Crops	0.10	0.4	0.11	0.4
Crops (climate adjusted)	n/a	0.50	n/a	0.70
Forest, climate	0.04 – 0.30	0.16 - 1.2	0.04 - 0.30	0.16 - 1.2
Forest production	0.02 - 0.03	0.07 - 0.11	0.02 - 0.03	0.07 - 0.11
Biodiversity (WTP)	0.51 - 1.5	0.91 - 2.7	0.61 - 1.8	1.0 - 2.9
Biodiversity (repair cost)	1.8	3.0	2.2	3.1
Biodiversity (Regulatory revealed preference)	(indicative 6.6)	11	(indicative 7.8)	11
Ecosystems range	**0.77 – 7.3**	**1.5 – 12.8**	**0.78 – 8.2**	**1.6 – 13.0**
Health	30	50	30	50
Health (range)	20 - 150	40 - 220	30 - 140	40 - 220

Overall, the ranges for ecosystem benefits add between around 3% and 25% to the estimate of potential benefit of the scenarios considered, with health benefits quantified using the 'mid value of a life year/VOLY' estimate (which as has already been noted is the most widely referenced in the European Commission's work in this field). The upper end of the range for ecosystems is dominated by the estimate for biodiversity protection based on the regulatory revealed preference approach. Leaving this aside, estimated benefits would be biased to the lower end of the ranges shown. For effects on crops and forests, potential benefits are limited by the small extent to which ozone levels can be reduced using the abatement options contained in the GAINS model.

It is useful to compare the above results with those generated in the European Nitrogen Assessment (Sutton et al, 2011), which provides a thorough review of the sources, flows and impacts of nitrogen in the European environment. Chapter 22 of the Assessment (Brink et al, 2011) provides information on costs and benefits. Results are shown in Table 27, including effects associated with releases of reactive nitrogen (N_r) to water and N_2O to air, though neither has been quantified in this report.

Table 27. Unit damage costs as €/kg reactive nitrogen for the major N_r pollutants. Upper figures, best estimate, lower figures range. From Brink et al (2011).

Pollutant	**Health**	**Ecosystems**	**Climate**	**Total**
N_r to water	1 0 – 4	12 5 – 20		13 5 – 24
NH_3-N to air	12 2 – 20	2 2 – 10		14 4 – 30
NOx-N to air	18 10 – 30	2 2 – 10		20 12 – 40
N_2O-N to air	2 1 – 3		9 5 – 15	11 6 – 18

The lower bound for ecosystem damage (also adopted as the best estimate) was based on the costs of restoring biodiversity loss due to reactive nitrogen deposition estimated by Ott et al (2006). The upper bound was arbitrarily set 5 times higher as a possible value when using an ecosystem service approach.

Direct comparison with the results presented here is not possible, given the difference in units. However, it is possible to compare the relative magnitude of health and ecosystem impacts. The lower bound estimates from Brink et al for health, particularly for NH_3 are not supported by analysis based on current recommendations from the World Health Organization (it is believed that Brink et al downgraded the risk from aerosol generated following release of NH_3, reflecting debate at the time that their estimates were made, but not a debate that has continued). However, the two sets of results agree that the health impacts are likely to be most significant. Leaving aside the arbitrary scaling of the Ott based result by a factor 5, there is again general agreement on the ratio of the lower bound ecosystem damage estimates to the health impacts.

It is logical to ask what our estimates of ecosystem damage add to the overall policy message emerging from the ECLAIRE work. We offer the following thoughts:

1. The analysis of crops highlights the importance of accounting for future changes in cropping patterns across Europe as a consequence of climate change, with some species (e.g. tomato) likely to be planted in greater quantity than at present, and others (e.g. wheat) making way for them to some extent. Comparing the 'climate adjusted' crop damage/benefit estimates above with the unadjusted values demonstrates an overall increase in sensitivity to ozone over time.
2. Analysis should be extended to include damage to livestock production and related products (milk, wool) as these account for 50% of the EU's agricultural output (though it is accepted that animal products may not be so sensitive to pollution effects, partly as negative impacts can be ameliorated using additional feed at a cost).
3. For forests the more important impact of the two assessed was of ozone reducing levels of carbon sequestration, as opposed to its impact on gross output of the forestry and logging sector. Estimates of the damage arising from reduced carbon sequestration increase markedly for the later scenarios given a step change in the values adopted for that period.
4. It is acknowledged that the valuation of carbon sequestration is problematic. The debate on appropriate values to adopt per tonne of CO_2 is not likely to go away soon. The values selected here were in part chosen to highlight the variation in available estimates from well-regarded sources and show at the lower-end effects of a similar magnitude to effects on production from forestry and logging. However, at the upper-end, results for climate mitigation are substantially greater.
5. The health impact assessment and valuation demonstrates the case for reducing air pollutant emissions across Europe. The numbers generated here for ecosystems, whilst smaller than those for health, show that other impacts are not inconsequential. This in turn indicates that policy can be made most efficiently if it focuses on a wider range of effects, beyond health, with potential added benefits in the order of €billions per year.

It is necessary to consider the validity of any of the methods for quantifying damage to biodiversity. Comments have already been made, principally about the validity of the repair cost approach and 'regulatory revealed preference' approach, with the willingness to pay (WTP) based estimates here considered superior from the perspective of economic theory. However, it has also been noted that even this approach is not without its flaws. The assumptions that individuals are able to either assess the full societal value of biodiversity, or pay for its protection, are, at best, questionable. A bid in a valuation study will be subject to a number of factors including ability to pay, and individuals may consider that additional improvements beyond what they can personally contribute to should be undertaken.

The result of the 'regulatory revealed preference' method in generating higher estimates implies that policy makers in setting the ultimate goal of European policy on biodiversity place a much higher value on ecological protection than members of the public. This goal, under Target 2 of the EU's Biodiversity Strategy to 2020, is phrased as 'no net loss of biodiversity or ecosystem services'. Of course, it is doubtful that they considered the costs of reducing air pollution when agreeing the policy, but far-reaching objectives like this rarely come cheap. As noted earlier, policy makers in this field are now better aware of the role of air pollution in ecosystem damage and the abatement costs involved, but have not adjusted their objective.

It is noted that the values used within each method for assessing biodiversity impacts are drawn from a limited literature. The WTP estimates could certainly be refined through surveys carried out in a number of countries, focused on deriving values that feed into assessment of marginal changes linked to developing policy. This is identified as the most pressing research need from this Work Package. Part of this work should seek to elucidate what members of the public know about the impacts of air pollution and threats to ecosystems more generally.

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